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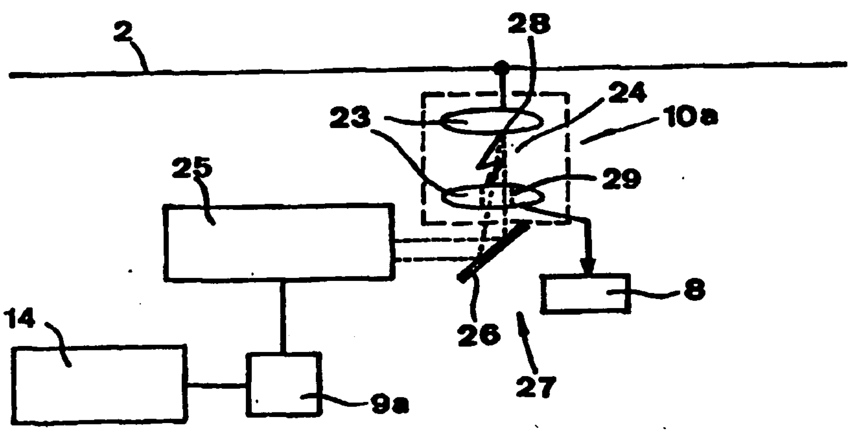
(54) Title: SWITCHING DEVICE INCLUDING SPARK GAP FOR SWITCHING ELECTRICAL POWER

(57) Abstract



A device for switching electric power comprises at least one electric switching arrangement (5). This switching arrangement comprises at least one switching element (10a) comprising an electrode gap (24). This gap is convertible between an electrically substantially insulating state and an electrically conducting state. Furthermore, the switching element comprises means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity. The means (25) for causing or at least initiating the electrode gap to assume conductivity are adapted to supply energy to the electrode gap in the form of radiation energy to bring the gap or at least a part thereof to the form of a plasma by means of this radiation energy.

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SWITCHING DEVICE INCLUDING SPARK GAP FOR SWITCHING ELECTRICAL POWER.

FIELD OF THE INVENTION AND PRIOR ART

This invention is related to a device according to the pre-characterising part of enclosed claim 1. The device according to the invention may be used in any connection for switching purposes. Particularly preferred are applications where high power is to be switched. In reality, high voltage connections and electric power transmission applications are involved. A preferred, but not restricting, application of the device according to the invention is to protect, in an electrical power plant, an electrical object from the consequences of faults, primarily as far as current is concerned but also voltage. Besides, the invention comprises a method for protection of the object.

The electric object in question may be of arbitrary nature as long as it is contained in an electric power network and requires protection against fault-related over-currents, i.e. in practice short-circuit currents. As an example, it may be mentioned that the object may be formed by an electric apparatus having a magnetic circuit, e.g. a generator, transformer or motor. Also other objects may be in question, e.g. power lines and cables, switch gear equipment etc. The present invention is intended to be applied in connection with medium and high voltage. According to IEC norm, medium voltage refers to 1-72,5 kV whereas high voltage is >72,5 kV. Thus, transmission, subtransmission and distribution levels are included.

In prior power plants of this nature one has resorted to, for protection of the object in question, a conventional circuit-breaker (switching device) of such a design that it provides galvanic separation on breaking. Since this circuit breaker must be designed to be able to break very high currents and voltages, it will obtain a comparatively bulky design with large inertia, which reflects itself in a comparatively long break-time. It is pointed out that the over-current primarily intended is the short-circuit current occurring in connection with the protected object, for instance as a consequence of faults in the electric insulation system of the protected object. Such faults means that the fault current (short-circuit current) of the external network/equipment will tend to flow through the arc. The result may be a very large breakdown. It may be mentioned that for the Swedish power network, the dimensioning short-circuit current/fault-current is 63 kA. In reality, the short-circuit current may amount to 40-50 kA.

A problem with said circuit-breaker is the long-break time thereof. The dimensioning break-time (IEC-norm) for completely accomplished breaking is 150 milliseconds (ms). It is associated to difficulties to reduce this break-time to less than 50-130 ms depending upon the actual case. The consequence thereof is that when there is a fault in the protected object, a very high current will flow through the same during the entire time required for actuating the circuit-breaker to break. During this time the full fault current of the external power network involves a considerable load on the protected object. In order to avoid damage and complete breakdown with respect to the protected object, one has, according to the prior art, constructed the object so that it manages, without appreciable damage, to be subjected to the short-circuit current/fault current during the break-time of the circuit breaker. It is

pointed out that a short-circuit current (fault current) in the protected object may be composed of the own contribution of the object to the fault current and the current addition emanating from the network/equipment. The own contribution of the object to the fault current is not influenced by the functioning of the circuit-breaker but the contribution to the fault current from the network/equipment depends upon the operation of the circuit breaker. The requirement for constructing the protected object so that it may withstand a high short-circuit current/fault current during a considerable time period means substantial disadvantages in the form of more expensive design and reduced performance.

As pointed out hereinabove, the invention is, however, not only restricted to protection applications. In other switching situations it is a disadvantage to have to resort to rather costly and bulky switching devices when high power is involved, for instance banks of semiconductor components, in order to manage the switching function aimed at. Thus, it would be desirable to achieve a rapidly operating switching device having a very good ability to conduct large currents.

OBJECT OF THE INVENTION

The primary object of the present invention is to provide a switching device better suited for switching high electric power in a rapid manner and to a comparatively low cost than switching devices used today.

A secondary object of the present invention is to devise ways to design the device and the method so as to achieve better protection for arbitrary objects and, accordingly, a reduced load on the same, a fact which means that the objects themselves do not have to be designed to withstand

a maximum of short-circuit currents/fault currents during relatively long time periods.

SUMMARY OF THE INVENTION

According to the invention, the switching arrangement is designed in accordance with the characterizing part of claim 1. Since the electrode gap of the switching means is brought to an electrically conducting state by supplying energy directly to the electrode gap proper in the form of radiation in order to establish ionisation/plasma in the electrode gap, conditions are created for a very rapid operation of the switching arrangement according to the invention. The ionisation/plasma in the electrode gap causes/initiates an electrically conducting plasma channel having a very high conductivity so that very large currents may be conveyed and this more specifically during relatively prolonged time periods without negative effects, which is in direct contrast to conventional semi-conductor art.

In the development work which preceded the invention, it has been established that conventional optical lens systems are associated to disadvantages as far as the direction of the radiant energy to the electrode gap is concerned. The larger proportion of the radiant energy that can be concentrated in areas or volumes preferable for trigging and located in the electrode structure under voltage, the more efficient and the more easy and with statistical certainty can the triggering be effected. Thus, it is very important that the radiation concentrating system used absorbs as little of the radiant energy as possible and that this system directs the incident radiant energy to the triggering volume intended with as high precision as possible. Optical lens systems have turned out to be deficient both with regard to absorption of radiant energy and difficulties to concentrate the same in an optimal manner.

According to the present invention it is preferred that the means for supplying triggering energy to the electrode gap comprise a system for directing to electromagnetic wave energy, said system having at least one diffractive element (DE) or alternatively at least one diffraction optical element (DOE).

According to the invention, the secondary object indicated above is achieved in that the switching arrangement in the form of an over-current reducing arrangement, which is actuatable for over-current reduction with assistance of an over-current conditions detecting arrangement, is connected to the electric power plant for protection of the object. The switching arrangement may, according to a preferred embodiment, form an over-current diverter for diverting overcurrents to earth or otherwise another unit having a relatively low potential.

Thus, the invention is based upon the principle, as far as the protection aspect is concerned, to utilise a rapidly operating switch arrangement, hereinafter called switch means, which without effecting any real breaking of the overcurrent, nevertheless reduces the same to such an extent that the object under protection will be subjected to substantially reduced strains and accordingly a smaller amount of damages. The reduced over-current/fault-current means, accordingly, that the total energy injection into the protected object will be substantially smaller than in absence of the switch means according to the invention.

The solution according to the invention based upon a switch means implies a particularly advantageous fulfilling of demands which may be set up in order to achieve a satisfactory protection function. Thus, a very rapid triggering may be achieved by the switch means so that occurring fault-related

over-currents with a very small delay in time will be diverted via the switch means as soon as the electrode gap has adopted an electrically conductive condition. It is pointed out that the term "triggering" in this connection means bringing the switch means into an electrically conducting state. By means of the arrangement of the switch means, said switch means may easily be dimensioned to be able to conduct very large currents. In order to obtain a satisfactory protection function it is, namely, desirable that the current conducting channel, which is established through the switch means, has a very low resistance. This means the largest possible strain-relieving of the object, which is to be protected from fault-currents. Besides, a switch means according to claim 1 may with a small effort be caused to function with a particularly high triggering safety. The triggering must not, in order to divert occuring fault-currents as soon as possible, therefore fail in a critical situation. The switch means according to the invention gives on the other hand rise to the possibility to dimensioning in order to achieve a very high electric strength in a non-triggered condition. The probability for a spontaneous breakthrough is thus to be at a minimum. It is especially preferred to thereby use at least one laser for triggering.

Preferable developments with respect to a.o. the means for supplying radiant energy to the electrode gap are defined in the enclosed claims. According to one embodiment, the radiant energy is supplied to the electrode gap in two or more spots or areas for the purpose of achieving the highest possible certainty with regard to bringing the electrode gap to assume an electrically conducting state. According to one alternative the energy supply means may be designed to supply the radiant energy along an elongated area in the conduction path which is aimed at between the electrodes. According to an optimal embodiment this elongated area may, entirely or substantially entirely, bridge the gap between

the electrodes. Although it is possible, in a case with two or more spots or areas for radiation supply, that these spots or areas are applied successively corresponding to the propagation with respect to the electrical conduction path between the electrodes in such a way that the spots or areas are successively applied with a time delay, it is, according to the invention, normally preferred to apply these spots or areas substantially simultaneously for making the electrode gap conducting momentarily.

Furthermore, the means for supply of triggering energy may according to the invention be adapted to apply the radiant energy in a volume having a tubular shape. This is particularly preferable when one of the electrodes comprises an opening, through which the radiant energy is supplied, and when the radiant energy supplied in a tubular volume is applied relatively close to the electrode provided with an opening.

According to an alternative embodiment, the energy supply means may be designed to supply the radiant energy in a plurality of substantially parallel, elongated areas extending between the electrodes.

The radiant energy may also be supplied to the electrode gap transversely relative to an axis of the electrodes in one or more spots located between the electrodes.

Diffraction is not a uniformly defined term within optics. It may be said to be a wave propagation phenomenon, which by interaction between the electromagnetic field distribution of an electromagnetic wave and matter, such as for instance a non-transparent aperture or a surface having a varying phase structure, changes the electric field distribution of the electromagnetic wave in the three dimensional space following after the light or the electromagnetic radiation.

A. Sommerfeld has defined diffraction as: "each deviation of light beams from straight paths, which can not be explained and interpreted as reflection or refraction". However, it can be shown that reflection and refraction only are special cases of diffraction if one contemplates the diffractive surface to be so small that it can be approximated with a plane. Mathematically, the diffraction phenomenon may be described with Huygen's principle or be derived starting from the scalar wave equation (which in turn may be derived from Maxwell's equations) for so-called scalar diffraction, where the polarization of the light is not considered and where the electrical vector field may be considered as a scalar field. The perhaps most used mathematically formulation of scalar diffraction theory is formed by Fresnel-Kirchoff's integral representation. Rigorous (vectorial) diffraction theory, which, in contrast, may deal with the influence of polarization, may also be derived from Maxwell's equations but leads often to considerably more complicated mathematical solutions.

Diffractive optics may be of holographic type or computer generated type. The last mentioned is denominated computer generated holograms. Computer generation means that the diffraction optical component has been calculated in a computer to control, on illumination with the light in question, this light to a certain specific and predetermined distribution in the three dimensional space. In the present specification, the optical components intended are summarized with the term DOE (Diffraction Optical Elements). Holographically generated diffractive optics is normally restricted to relatively simple functions, such as diffraction gratings. This type is produced in a holographic manner in that a desired interference pattern between light waves is registered photographically. Computer generation, on the other hand, admits a very large flexibility in the design of DOE.

Diffractive structures may of course also be realized for other electromagnetic radiant energy than light, which conventionally concerns electromagnetic radiation with wavelengths in the visible part of the spectrum. Such structures may be denominated DE - diffractive elements.

Further advantages and features of the invention, particularly with respect to the method according to the invention, appear from the following description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the enclosed drawings, a more specific description of an embodiment example of the invention follows hereinafter.

In the drawings:

Fig 1	is a purely diagrammatical view illustrating the basic aspect behind the solution according to the invention,
Figs 2a-2d	are diagrams illustrating in a diagrammatical form and in a comparative way fault current developments and the energy development with and without the device according to the invention;
Fig 3	is a diagrammatical view illustrating a conceivable design of a device according to the invention;
Fig 4	is a diagrammatical, detailed view illustrating a possible design of the switching arrangement as an over-current reducing arrangement

Figs 5 is a diagrammatical view illustrating the device according to the invention applied at an electrical power plant comprising a generator, a transformer and an electric power network coupled thereto,

Fig 6 is a very diagrammatical view similar to fig 1 with the switching arrangement according to the invention arranged in series,

Figs 7a and 7b are views indicative of peculiarities of diffractive elements,

Fig 8 is a view illustrating co-ordination of a diffractive element with electrodes in a switch means,

Fig 9 is a view illustrating a hypothetical diffractive surface relief, which may be a kinoform,

Figs 10a and 10b are views illustrating the function of a diffractive saw tooth grating having a continuous surface relief together with the function of a corresponding saw tooth grating having a discrete surface relief,

Figs 11a-11f are views indicating different energy or power density distributions for a diffractive element,

Figs 12a-12g are views illustrating energy or power density distributions with alternative designs of diffractive elements,

Fig 13	is a view illustrating an alternative optical system placed at the side of one of the electrodes,
Figs 14 & 15 resp.	are views form the side and in perspective of an embodiment with several diffractive elements placed around one of the electrodes,
Figs 16a-16e	are views illustrating how elongated focal areas may be achieved according to the invention, these elongated focal areas being illustrated in figs 16b-e as having different tubular shapes,
Figs 17a-17e	are views illustrating how several elongated focal areas may be achieved according to the invention,
Figs 18a and 18b	are views somewhat similar to the one in fig 8 but illustrating different designs and locations as far as diffractive elements end elongated focal areas achieved thereby are concerned.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An electric power plant comprising a protected object 1 is shown in Fig 1. This object could for instance consist of a generator. This object is connected, via a line 2, to an external distribution network 3. Instead of such a network, the unit denoted 3 could be formed by some other equipment contained in the electric power plant. The electric power plant involved is conceived to be of such a nature that it is the object 1 itself which primarily is in-

tended to be protected against fault currents from the network/equipment 3 when there occurs a fault in the object 1 giving rise to a fault current from the network/equipment 3 towards the object 1 so that the fault current will flow through the object. Said fault may consist in a short-circuit having been formed in the object 1. A short-circuit is a conduction path, which is not intended, between two or more points. The short-circuit may for instance consist of an arc. This short-circuit and the resulting violent current flow may involve considerable damages and even a total break-down of the object 1.

It is already pointed out that with at least some types of protected electrical objects 1, short-circuit currents/fault currents harmful to the object in question may flow from the protected object towards the network/equipment 3. Within the scope of the invention, it is intended to be used for protection purposes not only for protection of the object from externally emanating fault currents flowing towards the object but also from internal fault currents in the object flowing in the opposite direction. This will be discussed in more detail in the following.

In the following, the designation 3 will, to simplify the description, always be mentioned as consisting of an external electric power network. However, it should be kept in mind that some other equipment may be involved instead of such a network, as long as said equipment causes violent current flows through the object 1 when there is a fault.

A conventional circuit breaker 4 is arranged in the line 2 between the object 1 and the network 3. This circuit breaker comprises at least one own sensor for sensing circumstances indicative of the fact that there is an over-

current flowing in the line 2. Such circumstances may be currents/voltages but also other indicating that a fault is at hand. For instance, the sensor may be an arc sensor or a sensor recording short circuit sound etc. When the sensor indicates that the overcurrent is over a certain level, the circuit breaker 4 is activated for breaking of the connection between the object 1 and the network 3. The circuit breaker 4 must, however, break the total short circuit current/fault current. Thus, the circuit breaker must be designed to fulfil highly placed requirements, which in practice means that it will operate relatively slowly. In Fig 2a it is illustrated in a current/time-diagram that when a fault, for instance a short circuit in the object 1, occurs at the time t_{fault}, the fault current in the line denoted 2 in Fig 1 rapidly assumes the magnitude i_1. This fault current i_1 is broken by means of the circuit breaker 4 at t_1, which is at least within 150 ms after t_{fault}. Fig 2d illustrates the diagram $i^2 \cdot t$ and, accordingly, the energy developed in the protected object 1 as a consequence of the short circuit therein. The energy injection into the object occurring as a consequence of the short-circuit current is, accordingly, represented by the total area of the outer rectangle in Fig 2d.

It is in this connection pointed out that the fault current in Figs 2a-c and the currents in Fig 2d represent the envelope of the extreme value. Only one polarity has been drawn out in the diagram for the sake of simplicity.

The circuit breaker 4 is of such a design that it establishes galvanic separation by separation of metallic contacts. Accordingly, the circuit breaker 4 comprises, as a rule, required auxiliary equipment for arc extinguishing.

According to the invention the line 2 between the object 1 and the switching device 4 is connected to an arrangement

generally denoted 5. This arrangement may in general regard be designated as a switching arrangement. In the application shown, the switching arrangement has the function of an arrangement reducing overcurrents towards the apparatus. The arrangement is actuatable for overcurrent reduction with the assistance of an overcurrent conditions detecting arrangement within a time period substantially less than the break time of the circuit breaker 4. This arrangement 5 is, accordingly, designed such that it does not have to establish any galvanic separation. Therefore, conditions are created to very rapidly establish a current reduction without having to accomplish any total elimination of the current flowing from the network 3 towards the protected object 1. Fig 2b illustrates in contrast to the case according to Fig 2a that the overcurrent reducing arrangement 5 according to the invention is activated upon occurrence of a short circuit current at the time t_{fault} for overcurrent reduction to the level i_2 at the time t_2. The time interval $t_{fault}-t_2$ represents, accordingly, the reaction time of the overcurrent reducing arrangement 5. Since the task of the arrangement 5 is not to break but only reduce the fault current, the arrangement may be caused to react extremely rapidly, which will be discussed more closely thereunder. As an example, it may be mentioned that current reduction from the level i_1 to the level i_2 is intended to be accomplished within one or a few ms after unacceptable overcurrent conditions having been detected. It is then aimed at to accomplish the current reduction in a shorter time than 1 ms, and preferably more rapidly than 1 microsecond.

As appears from Fig 1, the device comprises a further breaker generally denoted 6 and arranged in the line 2 between the circuit breaker 4 and the object 1. This further br aker is designed to break a lower voltage and current than the circuit breaker 4 and may, as a consequence

thereof, be designed to operate with shorter break times than the circuit breaker. The further breaker 6 is arranged to break not until after the overcurrent from the network 3 towards the object 1 has been reduced by means of the overcurrent reducing arrangement 5 but substantially earlier than the circuit breaker 4. From that stated, it appears that the further breaker 6 should be coupled to the line 2 in such a way that it is the current reduced by means of the overcurrent reducing arrangement 5 which will flow through the further breaker and which, accordingly, is to be broken by means thereof.

Fig 2b illustrates the action of the further breaker 6. This breaker is, more specifically, designed to break at the time t_3, which means that the duration of the current i_2 reduced by means of the overcurrent reducing arrangement 5 is substantially delimited, namely to the time period t_2-t_3. The consequence is that the energy injection into the protected object 1 caused by a fault current from the network 3 is represented by the surfaces marked with oblique lines in Fig 2d. It appears that a drastic reduction of the energy injection is achieved. In this connection it is pointed out that since, according to a specific model, the energy increases with the square of the current, a reduction to one half of the current reduces the energy injection to a fourth. It is illustrated in Fig 2c how the fault current will flow through the arrangement 5.

The dimensioning of the arrangement 5 and the further breaker 6 is conceived to be carried out such that the arrangement 5 reduces the fault current and the voltage to be broken by means of the further breaker 6 to substantially lower levels. A realistic break time as to the further breaker 6 is 1 ms. However, the dimensioning should be made such that the breaker 6 is caused to break not until after the arrangement 5 having reduced the current

flowing through the breaker 6 to at least a substantial degree.

It is illustrated in more detail in Fig 3 how the device may be realised. It is then pointed out that the invention is applicable in direct current (also HVDC = High Voltage Direct Current) and alternating-current connections. In the latter case, the line denoted 2 may be considered to form one of the phases in a multiphase alternating-current system. However, it should be kept in mind that the device according to the invention may be realised so that either all phases are subjected to the protection function according to the invention in case of a detected fault or that only that phase or those phases where a fault current occurs are subjected to current reduction.

It appears from Fig 3 that the overcurrent reducing arrangement generally denoted 5 comprises an overcurrent diverter 7 for diverting overcurrents to earth 8 or otherwise another unit having a lower potential than the network 3. Thus, the overcurrent diverter may be considered as forming a current divider which rapidly establishes a short circuit to earth or otherwise a low potential 8 for the purpose of diverting at least a substantial part of the current flowing in the line 2 so that said current does not reach the object 1 to be protected. If there is a serious fault in the object 1, for instance a short circuit, which is of the same magnitude as the short circuit that the overcurrent diverter 7 is capable of establishing, it may be said that generally speaking a reduction to one half of the current flowing to the object 1 from the network 3 is achieved as a consequence of the overcurrent diverter 7 in case the fault is close to the latter. In comparison with Fig 2b, it appears, accordingly, that the current level i_2 illustrated therein and being indicated to amount to approximately half of i_1 may be said to

represent the worst occurring case. Under normal conditions, the purpose is that the overcurrent diverter 7 should be able to establish a short circuit having a better conductivity than the one corresponding to the short circuit fault in the object 1 to be protected so that accordingly a main part of the fault current is diverted to earth or otherwise a lower potential via the overcurrent diverter 7. It appears from this that, accordingly, in a normal fault case, the energy injection into the object 1 in case of a fault becomes substantially smaller than that which is indicated in Fig 2d as a consequence of lower current level i_2 as well as shorter time span t_2-t_3. It should be obvious that a certain protection is obtained also when a short-circuit, which has been established, has a somewhat lower conductivity than the one corresponding to the short-circuit fault in the object 1 to be protected.

It has been pointed out that the notation 8 not only includes earth but another unit with a lower potential than the network/equipment 3. It is thereby to be noted that the unit 8 possibly could be formed by another power network or another equipment included in the electric power plant, said equipment having a lower level of voltage than the one which is effective for the network/equipment 3, to which the object 1, which is to be protected, is connected.

The over-current diverter 7 comprises switch means coupled between earth 8 or said lower potential and the line 2 between the object 1 and the network 3. This switch means comprises a control member 9 and a switch member 10. This switch member is arranged to be open in a normal state, i.e. insulating in relation to earth. The switch member 10 may however be brought into a conductive state via the control member 9 in a very short time in order to establish current reduction by diversion to earth.

Fig 3 illustrates that an overcurrent conditions detecting arrangement may comprise at least one and preferably several sensors 11-13 suitable for detecting such overcurrent situations requiring activation of the protection function. As also appears from Fig 3, these sensors may include the sensor denoted 13 located in the object 1 or in its vicinity. Furthermore, the detector arrangement comprises a sensor 11 adapted to sense overcurrent conditions in the line 2 upstreams of the connection of the overcurrent reducing arrangement 5 and the line 2. As is also explained in the following, it is suitable that a further sensor 12 is provided to sense the current flowing in the line 2 towards the object 1 to be protected, i.e. the current which has been reduced by means of the overcurrent reducing arrangement 5. In addition, it is pointed out that the sensor 12, as well as possibly the sensor 13, is capable of sensing the current flowing in the line 2 in a direction <u>away</u> from the object 1, for instance in cases where energy magnetically stored in the object 1 gives rise to a current directed away from the object 1.

It is pointed out that the sensors 11-13 do not necessarily have to be constituted by only current and/or voltage sensing sensors. Within the scope of the invention, the sensors may be of such nature that they generally speaking may sense any conditions indicative of the occurrence of a fault of the nature requiring initiation of a protection function.

In cases where such a fault occurs that the fault current will flow in a direction away from the object 1, the device is designed such that the control unit 14 thereof will control the further breaker 6 to closing, in case it would have been open, and, in addition, the overcurrent reducing arrangement 5 is activated such that the short

circuit current may be diverted by means of the same. When, for example, the object 1 is conceived to consist of a transformer, the function on occurrence of a short circuit therein could be such that the short circuit first gives rise to a violent flow of current into the transformer, which is detected and gives rise to activation of the arrangement 5 for the purpose of current diversion. When the current flowing towards the transformer 1 has been reduced in a required degree, the breaker 6 is caused to break, but, controlled by means of the control unit 14, not earlier than leaving time for the energy, in occurring cases, magnetically stored in the transformer 1 to flow away from the transformer 1 and be diverted via the arrangement 5.

Furthermore, the device comprises a control unit generally denoted 14. This is connected to the sensors 11-13, to the overcurrent reducing arrangement 5 and to the further breaker 6. The operation is such that when the control unit 14 via one or more of the sensors 11-13 receives signals indicating occurrence of unacceptable fault currents towards the object 1, the overcurrent reducing arrangement 5 is immediately controlled to rapidly provide the required current reduction. The control unit 14 may be arranged such that when the sensor 12 has sensed that the current or voltage has been reduced to a sufficient degree, it controls the breaker 6 to obtain operation thereof for breaking when the overcurrent is below a predetermined level. Such a design ensures that the breaker 6 is not caused to break until the current really has been reduced to such a degree that the breaker 6 is not given the task to break such a high current that it is not adequately dimensioned for that purpose. However, the embodiment may alternatively also be such that the breaker 6 is controlled to break a certain predetermined time after the

overcurrent reducing arrangement having been controlled to carry out current reduction.

The circuit breaker 4 may comprise a detector arrangement of its own for detection of overcurrent situations or otherwise the circuit breaker may be controlled via the control unit 14 based upon information from the same sensors 11-13 also controlling the operation of the overcurrent reducing arrangement.

It is illustrated in Fig 3 that the further breaker 6 comprises a switch 15 having metallic contacts. This switch 15 is operable between breaking and closing positions by means of an operating member 16, which in turn is controlled by the control unit 14. A shunt line 17 is connected in parallel over this switch 15, said shunt line comprising one or more components 18 intended to avoid arcs on separation of the contacts of the switch 15 by causing the shunt line 17 to take over the current conduction from the contacts. These components are designed so that they may break or restrict the current. Thus, the purpose is that the components 18 normally should keep the conduction path in the shunt line 17 interrupted but close the shunt line when the switch 15 is to be opened so that accordingly the current is shunted past the switch 15 and in that way arcs do not occur or possibly occurring arcs are efficiently extinguished. The components 18 comprise one or more associated control members 19 connected to the control unit 14 for control purposes. According to one embodiment of the invention, said components 18 are controllable semiconductor components, for instance GTO thyristors, having necessary over-voltage arresters 30.

A disconnector 20 for galvanic separation in the current conduction path created by means of the shunt line 17 to the object 1 to be protected is arranged in series with

said one or more components 18. This disconnector 20 is via an operating member 21 controlled by the control unit 14. The disconnector 20 is illustrated in Fig 3 as being placed in the shunt line 17 itself. This is of course not necessary. The disconnector 20 could also be placed in the line 2 as long as it ensures real galvanic separation, by series coupling with said one or more components 18, in the conduction path established by means of said series coupling so that accordingly there is not any possibility for current to flow through the components 18.

The device as it has been described so far operates in the following manner: In absence of a fault, the circuit breaker 4 is closed just like the switch 15 of the further breaker 6. The components 18 in the shunt line 17 are in a non-conducting state. The disconnector 20 is closed. Finally, the switch means 10 of the overcurrent reducing arrangement 5 is open, i.e. it is in a non-conducting state. In this situation the switch means 10 must, of course, have an adequate electrical strength so that it is not inadvertently brought into a conducting state. Overvoltage conditions occurring in the line 2 as a consequence of atmospheric (lightning stroke) circumstances or coupling measures may, accordingly, not involve the voltage strength of the switch means 10 in its non-conducting state to be exceeded. For this purpose it is suitable to couple at least one over-voltage arrester 22 in parallel with the switch means 10. In the example such over-voltage arresters are illustrated on both sides of the switch means 10. Accordingly, the over-voltage arresters have the purpose to divert such overvoltages which otherwise could involve a risk for inadvertent breakthrough in the switch means 10.

The over-voltage diverters 22 are illustrated in Fig 3 to be connected to the line 2 itself on either sides of the con-

nection of the switch means 10 to the line. It is in principle desirable that at least one over-voltage diverter has its connection as close as possible upstreams in relation to the switch means 10. The over-current diverters 22 could instead, which is indicated in Fig. 3 with the dotted lines 26 be connected to the branch line forming electric connection between the switch means 10 and the line 2. Such a construction enables integration of the switch means 10 and at least one over-voltage diverter 22 to one single electric apparatus, which apparatus may be brought in electric conducting connection with the line 2 via one single connection.

When an over-current state has been registered by means of some of the sensors 11-13 or the own sensor (it is of course realized that information from the own sensor of the circuit breaker 4 may be used as a basis for control of the over-current reducing arrangement 5 according to the invention) of the circuit breaker 4 and this over-current state is of such magnitude that a serious fault of the object 1 is expected to be at hand, a breaking operation is initiated as far as the circuit breaker 4 is concerned. In addition, the control unit 14 controls the over-current reducing arrangement 5 to effect such reduction, and this more specifically by bringing, via the control member 9, the switch means 10 into an electrically conducting state. As described before, this may occur very rapidly, i.e. in a fraction of the time required for breaking by means of the circuit breaker 4, for what reason the object 1 to be protected immediately is liberated from the full short-circuit current from the network 3 as a consequence of the switch means 10 diverting at least an essential part, and in practice the main part, of the current to earth or otherwise a lower potential. As soon as the current, which flows towards the object 1 via the further breaker 6, has been r duced in a required degree, which can be established on a pure time basis by a time

difference between activation of the switch means 10 and operation of the breaker 6, or by sensing of the current flowing in the line 2 by means of, for instance, the sensor 12, the operating member 16 of the switch 15 is, via the control unit 14, controlled to open the contacts of the switch 15. For extinguishing or avoiding arcs, the components 18, e.g. GTO thyristors or gas switches, are via the control members 19 controlled to establish conductivity of the shunt line 17. When the switch 15 has been opened and, thus, provided galvanic separation, the component 18 is again controlled to bring the shunt line 17 into a non-conducting state. In that way the current from the network 3 towards the object 1 has been efficiently cut off. After having brought the shunt line 17 into a non-conducting state, galvanic separation may, in addition, be effected by means of the disconnector 20 by controlling the operating member 21 thereof from the control unit 14. When all these incidents have occurred, breaking by means of the circuit breaker 4 occurs as a last incident. It is important to note that the over-current reducing arrangement 5 as well as the further breaker 6 according to a first embodiment can be operated repeatedly. Thus, when it has been established by means of the sensors 11-13 that the circuit breaker 4 has been brought to cut off, the switch means 10 is reset to a non-conducting state and the switch 15 and the disconnector 20 are again closed so that when the circuit breaker 4 next time closes, the protection device is completely operable. According to another embodiment, it is, however, contemplated that the over-current reducing arrangement 5 may require exchange of one or more parts in order to operate again.

It is pointed out that according to an alternative embodiment of the invention, the component or components 18 could be brought into a conducting state as soon as the

over-current reducing arrangement 5 has been brought into a closing state and this independently of whether the switch 15 possibly is not opened thereafter. The control of the components 18 could then, as described before, occur via the control unit 14 or, alternatively, by means of a control function involving a slavish following of the closing of the arrangement 5.

Fig 4 illustrates a first embodiment of the over-current reducing arrangement 5 with switch means denoted 10a. The switch means 10a has electrodes 23 and a gap 24 prevailing between these electrodes. The switch means as it has been described so far has means 25a in order to trigger the electrode gap 24 to form an electrically conducting path between the electrodes. A control member 9a is arranged to control the operation of the members 25a via the control unit 14a. The means 25a are in the example arranged for causing or at least initiating the electrode gap to assume electrical conductivity by means of causing the gap or part thereof to form a plasma. It is thereby essential that the means 25a are capable of realising a very rapid supply of triggering energy to the electrode gap. It is thereby preferred that the triggering energy is supplied in the form of radiative energy, which in turn is capable of effecting ionising/initiating of plasma in the electrode gap.

The means 25a comprises according to a preferred embodiment of the invention at least one laser, which by means of energy supply to the electrode gap causes ionising/forming of plasma in at least a part of the electrode gap.

It is preferred in accordance with the invention to supply, with the aid of one or several lasers or other means 25a, energy to the electrode gap 24 in such a way that the complete electrode gap will be ionised and brought to the form of a plasma respectively, approximately momentarily in a way

that also the complete gap 24 immediately is brought to electrical conductivity. In order to spare with and optimize the use of the (normally) restricted available laser energy/-effect, the means 25a may, in application of the invention, be arranged so that they can provide ionization/plasma formation in only one or more parts of the gap 24. As will be described later, the invention also comprises application of the radiant energy in a plurality of spots or areas in the electrode gap, including also on one of or both of the electrodes, or in one or more rodlike areas extending continuously or substantially continuously between the electrodes.

By connecting the switch means 10a between the line 2 and earth 8 (or another unit with lower potential) as is diagrammatically indicated in Fig 4, i.e. with one of the electrodes 23 connected to the line 2 and the other electrode connected to earth 8, there will be a voltage difference between the electrodes causing an electric field. The electric field in the gap 24 is intended to be utilised in order to convey or cause an electric breakdown between the electrodes as soon as the means 25a have been controlled to triggering, i.e. have given rise to ionising/forming of plasma in one or more parts of the electrode gap. The established ionising/forming of plasma will be driven by the electric field to shunt the gap between the electrodes in order to in this way give rise to a low-resistant electrical conductive channel, i.e. an arc between the electrodes 23. It is pointed out that the invention is not intended to be restricted to use in connection with occurence of such an electric field. Thus, the intention is that the means 25a should be capable of establishing electrical conduction between the electrodes also without such a field.

Due to the demand on the switch means 10a to close very rapidly for current diversion, it is thus desirable when only a restricted part, e. g. a spot like part of the gap is ionised that the switch means is dimensioned in such a way that the strength of the electric field in the gap 24 will be sufficiently high for safe closing. It is however on the other hand a desire that the switch means 10a should have a very high electric strength against breakdowns between electrodes in its isolating rest position. The strength of the electric field in the gap 24 should therefore be proportionally low. This will, in one-spot ionisation, on the other hand reduce the speed, with which the switch means may be caused to establish the current diverting arc between the electrodes. In order to achieve an advantageous relation between the desire for a safe trigging of the switch means and on the other hand high electric strength against undesired trigging, it is according to the invention preferred that the switch means is formed in such a way that regarding its complete operational environment the electric field in the gap 24 has a field strength which is not more than 30% of the field strength at which a spontaneous breakdown normally takes place, when the gap forms electric isolation. This causes a proportionally low probability of a spontaneous breakdown.

The strength of the electric field in the electrode gap 24 in its isolating state is suitably not more than 20% and preferably not more than 10% of the field strength at which a spontaneous breakdown normally takes place. In order to on the other hand achieve an electric field in the electrode gap 24, which promotes forming of an arc at initiation of ionising/forming of plasma in a part of the electrode gap in a relatively rapid way, it is preferred that the strength in the electric field is at least 0,1% and suitably at least 1%, and preferably at least 5% of the field strength, at which a spontaneous breakdown normally takes place.

The electrode gap 24 is, as may be seen in Fig. 4, enlcosed in a suitable casing 32. A vacuum as well as a suitable medium in the form of gas or even fluid may for this purpose be present in the gap 24. In the case of a gas/fluid the medium in the gap is intended to be formed in such a way that it might be ionised and brought to plasma by triggering. It would in such a case be suitable to initiate ionisation/forming of plasma in the gap 24 at a point somewhere between the electrodes 23. It is however in Fig 4 illustrated the conceived case where there either is a vacuum or a suitable medium in the gap 24. It is then preferred that initiation of closing takes place by way of making the laser 25a, which is illustrated in Fig 4, to focus the emitted radiative energy in at least one area 28 on or in the vicinity of one of the electrodes via a suitable optical system 27. This implies that the electrode will operate as an electron and ion emitter for establishing an ionised environment/a plasma in the electrode gap 24 in such a way that thus an arc will be formed between the electrodes. One of the electrodes 23 may according to Fig 4 have an opening 29, through which the laser 25a is arranged to emit the radiative energy to the area 28 with support of the optical system 27.

In order to obtain the conditions discussed hereinabove as far as the field strength relations between the electrodes 23 in the isolating state of the switch means are concerned, the characteristics of the switch means should of course be adequately adjusted to the intended situation of use, i.e. the voltage conditions which will exist over the electrodes 23. The structural measures which are available concern, of course, electrode design, distance between electrodes, medium between electrodes and the occurrence of possible additional field influencing components between the electrodes.

Fig 5 illustrates an embodiment where a generator 1b is connected to a power network 3a via a transformer 1a. The objects which are to be protected are therefore represented by the transformer 1a and the generator 1b. The over-current reducing arrangement 5a and the further breaker 6a as well as the ordinary circuit breaker 4a are apparently arranged in resemblance with what is evident from Fig 1 in the case that the object 1 in Fig 1 is conceived to form the object 1a according to Fig 19. It is therefore in this regard referred to the descriptions in connection to Fig 1. The same is true for the protection operation of the over-current reducing arrangement 5c and the further breaker 6c in relation to the generator 1b. The generator 1b should therefore in this case be equivalent to the object 1 in Fig 1 while the transformer 1a should be equivalent to the equipment 3 in Fig 1. The over-current reducing arrangement 5c and the further breaker 6c will therefore in combination with the conventional circuit breaker 4b be able to protect the generator 1b against a violent current flow in the direction from the transformer 1a.

Fig 5 also illustrates the further over-current reducing arrangement 5b with the associated further breaker 6b. Apparently, over-current-reducing arrangements 5a and 5b will therefore be arranged on either sides of the transformer 1a. It is to be noted that the further breakers 6a and 6b, respectively are positioned in the connections between said over-current reducing arrangements 5a and 5b and the transformer 1a. The further over-current reducing arrangement 5b is intended to protect the transformer 1a from violent current flows towards the transformer from the generator 1b. The circuit breaker 4b will apparently be capable of breaking independently of in which direction between the objects 1a and 1b a protection function is desired.

Figs 6 illustrates diagrammatically how a switching arrangement 5 d is coupled in series in the previously mentioned line 2d between the network 3d and the object 1d. The switching arrangement 5d comprises suitably a coupling means 10d having the previously described character, i.e. a switching means having an electrode gap intended to be brought into electrically conductive closing by means of radiant energy. This is, however, not more closely shown in fig 6. As appears form fig 6, the switching arrangement 5d is intended to have a purely switching function, i.e. the feeding of the object 1d or possibly feeding in the opposite direction may occur via the switch means 10d when this is in a conducting state. When there is a need therefor, the switching means 10d may be caused to inhibit current flow relatively rapidly, for instance for protecting the object 1d or possibly even the network 3d from current flow from the object 1d. In order to obtain switching-off in alternating current connections by means of the switching means 10d it is sufficient that the means for energy supply to the electrode gap are caused to cease with such energy supply. On the subsequent passage through zero, the arc in the switch means 10d is intended to be extinguished such that current flow ceases. In direct current applications it would appear to be necessary to support the break function by taking measures to reduce or eliminate the voltage difference over the switch means 10d. Such a measure may consist in an electric switch 31 coupled in parallel over the switch means 10d. Closing of the electric switch 31 means that the current is shunted past the switch means 10d, which means that the arc in the switch means 10d is extinguished. Unless such a measure would be sufficient, it would be possible as a complement thereto to arrange further electric switches on either sides of the switch means 10d in line 2d in order to totally disconnect the switch means 10d from the line 2d. The purpose of fig 6 is to illustrate that the switch arrangement 5d according to the invention may find general

switching applications, in which it may be the question of protecting various apparatus but also of switching, more generally, power in various load situations.

Diffractive optical elements may be used in connection with the invention. Diffractive optical elements are elements, in which the light wave fronts, which determine the propagation of the light, are formed by diffraction rather than refraction. A diffraction optical component, DOE, may be realized by means of either amplitude control, phase control or both. A diffraction optical component of the first nature may be called an amplitude-DOE. Components of the second nature may be denominated phase holograms, phase-DOE:s, or more generally, phase controlling diffractive components.

The present patent is basically directed towards computer generated, purely phase controlling diffraction optical components. Phase control of light from a plane or a surface with a main orientation perpendicularly to the incident light may then be realized in, primarily, two manners: by means of refractive index modulation or by means of surface relief modulation. For transmitting DOE:s, both types of phase control are possible. For reflecting DOE:s, only surface relief modulation is of a directly practical interest. Phase control means that the resulting component presents a very high transmission, and accordingly a very low absorption, since the component is entirely in absence of a deliberate amplitude modulating function. The absorption, which the phase controlling component nevertheless presents, derives only from bulk absorption in the material, from which the DE/DOE is manufactured, and this absorption is typically less than 10%. Thus, the available light or radiation effect or energy may be utilized more efficiently. The low absorption admits that the component may be used for very high optical energies and effects, for instance emanating from high power lasers, without being damaged by thermal effects.

The phase difference $\Delta\Phi$ between a part light beam passing such a surface through its highest relief part and a part light beam passing the lowest relief part of the surface may generally be described as:

$$\Delta\Phi=\Delta(k\ z) = k\ \Delta z + \Delta k\ z$$

where $k=2\pi/\lambda_0$ and λ_0 is the light wavelength. In the case of a surface relief, k and z vary simultaneously, for what reason one obtains:

$$\Delta\Phi=\Delta(kz) = (2\pi/\lambda_0)(n_k-n_o)h$$

where h is the maximum relief height. If it is desired, as is common in diffraction optical design, to assure that the phase difference is $\Delta\Phi = 2\pi$, it results that the required relief height should be:

$$h = (m\lambda_0)/(n_k-n_0)$$

where n_k = the refractive index of the phase controlling substrate, n_0 is the refractive index of the surrounding medium, λ_0 is the wave length of light in vacuum and m is an integer or a rational number, preferably larger than ½.

(i) A substrate, which is of a thick material as compared to the intended light wave length, may, with various methods, be given a refractive index profile in a plane or over a surface defined by said material substrate, said refractive index profile providing the phase control function aimed at. This may be made for instance by electron, photon, ion or other radiation achieving a structural change of the substrate material so that it spatially, and in a plane, substantially perpendicularly orientated relative to the direction of the incident light, gives the phase controlling

function aimed at. It should be pointed out in this connection that it is very difficult to obtain such a phase controlling structure with required accuracy.

(ii) Another way of realizing a phase controlling structure is to modulate in phase the incident light by means of a surface relief. This appears clearly from that stated hereinabove. Such a surface relief may be realized by means of methods which are known and developed for, and within, the micro electronics industry, such as photo lithography, electron beam lithography or laser lithography. An example of such a surface relief is illustrated in fig 9.

It is pointed out that it is basically illustrated in figs 7a and 7b how diffractive elements 36e may be used for redirecting incident light diagrammatically indicated to the left into a quite different and almost arbitrary three-dimensional distribution. It is indicated in fig 7a how focal spots 28 distributed about the axis Z of symmetry may be obtained whereas fig 7b illustrates something which is normally more essential to the present invention, namely a series application of focal spots or areas 28e. In application of the invention, these spots or areas 28e are specifically intended to be located such that a rapid and efficient closing of the current conduction in the electrode gap can be achieved.

The most simple example of a DE/DOE is the linear diffraction grating. A purely phase controlling such grating may consist of a series of closely located "scribings" forming a surface relief. The width of the scribings, the period of the grating, is in this case constant. A transparent grating of this nature deflects incident radiation energy and light in a plurality of different so-called diffraction orders and, accordingly, in a plurality of different directions. The angle deflection is determined by the grating period and

of the wavelength of the light and may described with the so-called grating equation. A more sophisticated variant is a "blazed" grating; a saw tooth grating. In such a grating the relief within each period forms a sloping plane. This grating may be made to deflect incident light in one single direction. In order to obtain a good function, the relief height may be made to be of the same order as the light wavelength, or (often) an integer multiple thereof. The grating period is chosen based on how large an angle deflection is required for light of a specific wavelength. Such gratings, of transmission as well as reflection type, are used as the spectrally analysing element in spectrometres, in which the grating period may be for instance 1 000 lines/cm, which corresponds to the period length 10 μm.

Another well-known example of a simple DE/DOE is the Fresnel lens. Such a component in surface relief embodiment consists of a concentric surface relief, the grating period of which decreases with increasing distance from the centre of the lens relief. A Fresnel lens may be designed with a combination of a large aperture and a short focal length, so that the F-number thereof becomes close to 1 or less. This is difficult to achieve with a conventional refractive lens. Fresnel lenses are therefore a.o. used in applications where a great light gathering ability is required.

A kinoform is a DE/DOE in the form of a computer-generated hologram which only affects the phase of incident light. Phase influence is achieved by variation of the refractive index of the kinoform or by a shallow surface relief in one surface thereof. Kinoforms may be used to create, with high efficiency, arbitrary, desired and predefined light intensity distributions. The kinoform is calculated in a computer such that the wave fronts of the light leaving the kinoform obtain a certain desired shape. By diffraction of the light from the kinoform the predetermined intensity distribution

is achieved. It is only with modern micro lithography technique that kinoforms may be produced, e.g. in the form of micro surface relief lenses, optical correction plates and certain gratings and beam dividers.

A kinoform intended for transmission consists typically of a thin plate of a material transparent to the light intended or the electromagnetic radiation intended, with a surface relief on one side. The surface relief may have been achieved by for instance etching. The surface relief is to its structure very microscopic, with the smallest lateral details not much larger than the light wavelength. The same is due for the vertical dimensions. The kinoform controls/redirects incident light by diffraction in this surface structure. (It is understood, as mentioned, that a different way of realizing kinoforms is to change the refractive index of the material of the thin plate in a microscopical scale). In both these cases the light is, accordingly, controlled by change of the phase thereof. Figs 10a and 10b illustrate diagrammatically how a kinoform may have the character of a saw tooth grating of different design.

As already has been pointed out, the diffractive surface relief structure in a DE/DOE may be designed for transmission as well as for reflection.

Amplitude controlling structures are easily realizable by e.g. photographic technique. Phase controlling surfaces are, however, not as simple to achieve. A relief having a continuously varying height and a controllable shape may today possibly only be produced in very special cases. For instance, the saw tooth grating may be produced by means of mechanical ruling, where the sloping surfaces of the grating periods are obtained by mechanical processing, grating period after grating period. A generally two-dimensional surface relief may not be produc d in this way for such wave-

lengths of the electromagnetic radiation which reside within the infrared, visible or ultraviolet wavelength ranges.

With modern micro lithographic methods, for instance such which have been developed by and for the semi-conductor and microelectronics industry, two-dimensional surface reliefs may in contrast be produced with high accuracy. Examples of such methods are the already mentioned electron beam lithography EBL, laser lithography LBL and photolithography PL. The pattern or the relief to be produced is generated in a computer, the end result of which is used to control the lithographic instrument. In modern EBL and LBL, the surface structure is produced by sweeping an electron beam or a laser beam in a desired pattern over the relief surface to be formed - a substrate of suitable material having been coated by a layer of a so-called resist. The resist is a material effected by the radiation such that the solubility thereof in a developing liquid depends upon the exposed radiation dose. By varying the radiation dose over the resist surface, a surface relief is obtained after development. For practical and manufacturing reasons, the number of possible dosage levels and, accordingly, the number of possible vertical relief levels are restricted. For other practical reasons, for instance restrictions in the computer storing capacity of calculating and control computers, the exposed pattern is made discrete in a chessboard pattern of unitary cells, within which the exposed radiation dose is constant or almost constant. Also other geometrical divisions of the pattern are used, for instance circular. A resulting surface relief will, accordingly, have a discrete, steplike structure.

If only two relief levels are used, a binary relief is obtained. A binary DE/DOE is capable of deflecting at a maximum 40.5% of the incident radiation in a predefined intensity distribution. If more than about 8 relief levels are

used, the relief with very good accuracy will approximate a continuously varying surface, which gives a very good optical function and efficiency. A DE/DOE in the form of a multi level relief controls, accordingly, the phase of the radiation much more efficiently and 80-90% or more of the radiant energy may be deflected to the predefined intensity distribution.

Advantages of diffractive optics

The radiation or light is, hereinafter as well as hereinbefore, presupposed to propagate generally in z-direction in a cartesian coordinates system and the intensity variations (which here may represent power density and energy density/intensity variations) thereof may be achieved in z-direction as well as in arbitrary x-y-planes perpendicular to the z-axis. Diffractive components provide a great freedom to spatially control electromagnetic radiation energy:

- Almost arbitrary spatial intensity focal distributions may be achieved:
  - Longitudinally: Intensity variations with respect to the z-coordinate may be controlled.
  - Transversely: Focal spots and distributions may be placed relatively arbitrarily in the three-dimensional space.
  - Transversely: Several parallelelongated foci may be achieved. This enables generation of a plurality of parallel ionised plasma channels. Positive consequences are:
- Reduced electrode wear by lower arc current in each channel.
- A reduced total arc impedance.
- More rapid triggering.
- Focal distributions may be obtained which simply can not be realized at all with conventional refractive and reflective optics.

- Also non-circular symmetrical intensity distributions may be generated.
- The DE/DOE-component is small, lightweight, dielectrical, has a very high radiation and optical transparency and provides for a very great design flexibility.
- A DE/DO-component may in design be adjusted to the electrode arrangement, in which an electrical short-circuit is to be achieved, in order to optimize the short-circuit function aimed at.
- A DE/DOE-component in the form of a surface relief may, in distinction to conventional (optical) components, be mass-produced with low reproduction cost. The reproduction may be achieved with the same methods as those used in manufacturing of optically readable CD:s (Compact Discs).

In application in connection with the present invention, the following aspects are intended to be considered with the assistance of DE/DOE:

(i) The lowest triggerable electrode voltage is minimized.

(ii) The short-circuit time (from the arriving energy pulse to an entirely developed short-circuit) is minimized.

(iii) The triggering probability is maximized.

(iv) The probability of a spontaneous electrical break-through is chosen to be minimum in each application design.

(v) The radiant energy available for triggering is used in an optimum manner, in particular with regard to restricted available laser energy.

This is to be achieved as efficiently as possible in all regards using the available laser power or laser energy, which of course, and with necessity, is restricted.

The diffractive component (-s) which, possibly together with other conventional (optical) components, provide for focusing of the radiant energy enable possibilities to fulfil the above functions. It should be emphasized particularly that by using DE/DOE for concentration/focusing of radiant energy, the design of the electrode system may be simplified, and optimized, substantially, which appears from the following description.

By means of diffractive elements and diffractive optical elements, DE/DOE:S, very common energy density distributions (intensity distributions) may be achieved, which to a high degree may be made to optimize the short-circuiting function which is aimed at in an electrical protection system of the kind described. Since one of the main objects is to achieve a short-circuit between at least two electrodes which are separated a certain distance in gas or liquid atmosphere (or of vacuum, which, however, requires a somewhat different structure) and since the capacity (effect as well as energy; denominated radiant energy) of the radiation source used to generate the radiant energy required for achieving initiation ("triggering") of an electrical discharge in the electrode gap in question, with necessity is restricted, it is of the utmost importance that this available radiation energy is used as efficiently as possible. A first, and very natural, approach is to concentrate the radiation energy to an area which is as geometrically narrow as possible, said area being made to extend all the way between the, in this example, two main electrodes, between which the main part of the electrical system voltage to be short-circuited is present. Thus, in the first instance an elongated area is intended, in which the radiation energy is concentrated. This area is hereinafter denominated focal area. The elongated focal area generated by DE/DOE is provided between for instance two electrodes 23f (see fig 8) surrounded by gas or liquid, between which electrodes en electric voltage is ap-

plied. When radiant energy is supplied to the DE/DOE 36f and focused in the focal area by means thereof, a plasma channel is formed along the focal area, provided that the energy density of the radiation along the focal area exceeds the threshold energy density for radiation generated ionisation and plasma formation. This plasma channel will present a fairly good conductivity/electrical conductivity, for what reason charge transport may occur along the plasma channels. The electrodes 23f are short-circuited in this way.

In the following main points (I)-(VII) are discussed and exemplified, where the use of diffractive optics to concentrate radiant energy allows for substantial possibilities and advantages to achieve, by concentration of radiation energy, short-circuiting between two or more electrodes in a protecting device intended for e.g. en electric power network.

(I) The distribution of radiant energy may be achieved in one or more elongated focal areas. A very attractive alternative to a single focal area is a plurality of parallel focal areas, which alternative is dealt with hereinafter.

(II) By means of diffractive optics, continuous and discrete (i.e. not coherent in space) intensity distributions (power density distributions, unity: [Watt/m^2]) or energy density distributions (unit [Joule/m^2] hereinafter denominated "energy density distributions") may be achieved. This type of distribution is in the following denominated "longitudinal" distribution since it describes the energy density distribution in a direction parallel to the main direction of propagation of the radiant energy.

Fig 11a-f illustrates some continuos longitudinal distributions I(z) which can be generated with diffractive components DE/DOE. The optical intensity along the longitudinal

axis of symmetry, in each parallel channel, is predefined to vary in a manner which optimizes the electrically short-circuiting function of the DE/DOE-component mounted in a certain electrode arrangement. For example, it may be mentioned that it may be very interesting for triggering to concentrate a higher energy density on at least one of the surfaces of the electrodes in order to deliberate (for instance by so-called ablation) an increased amount of carriers of free charges, which carriers may simplify and take part in the short-circuiting process.

Figs 12a-g exemplifies a few corresponding discrete longitudinal energy density distributions obtained by DE/DOE with multi focal function. The energy densities in each discrete focal spot may be given an individual weight, whereby the envelope of the top values may be given a very common functional form. The discrete focal points may of course be positioned at an arbitrary distance from each other, restricted only by the manufacturing method and the (transversal) resolution, according to which the DE/DOE used has been manufactured. It is to be emphasized that in a discrete elongated focal distribution, a larger amount of the available radiant energy may be distributed in each discrete focal spot than the radiant energy in each spot in a continuous focal distribution with the same dimensions as the discrete one. This allows the available radiant energy to be used in an optimum manner for the purpose.

An attractive procedure is to design a DE/DOE resulting in a quasi-discrete focal distribution; a multi focal distribution in which adjacent discrete focal spots partly overlap each other. The energy density between adjacent focal spots is, accordingly, not allowed to be zero. It may, however, still be maintained above the threshold energy density for radiation initiated ionisation for the gas in question. A

direct gain therewith is a more efficient use of the radiant energy which is available to a restricted degree.

(III) Two preferred types of focal areas are formed by so-called cylindrical and tubular areas. A cylindrical focal area has a radiant energy distribution-presenting maximum along a line or a curve in the space. An example is a focal distribution along a straight line, the energy density distribution transversely to this line being Gauss shaped. A tubular focal area may, as is indicated in figs 16b-e have a radiant energy distribution presenting minimum along the axis of symmetry of the focal area and assuming maximum outwardly of this axis. In the example in fig 16c a focal distribution is shown where the energy density distribution of the radiation adopts maximum along a cylinder at a certain radial distance from a straight line. Such energy density distributions may be convergent (the typical radius of which decreases with an increased distance from the DE/DOE), divergent (the typical radius of which increases with an increased distance from the DE/DOE) or collimated (the typical radius of which is constant, independently of the distance from the DE/DOE).

It must be considered as a self-evident extension that also tubular focal areas may be formed by continuous as well as discrete and "quasi-discrete" respectively energy density distributions.

(IV) Another type of preferred embodiment (figs 17a-17e) is the provision of a plurality of parallel-elongated focal areas. Such a configuration is, accordingly, discretisized transversely of the main direction of propagation of the radiant energy. If this direction is formed by the z-axis in a cartesian coordinates system, a plurality of variants is conceivable. One or more parallel elongated focal areas may be positioned along the x-axis or another conceived line

parallel thereto. Alternatively, one o more parallel elongated focal areas may be positioned along the y-axis or another conceived line parallel thereto. A further alternative is to generate a plurality of parallel-elongated focal areas, which, transversely to the main direction of propagation of the radiation, are arranged in a two-dimensional matrix having an arbitrary distance in x- and y-direction between the different focal areas. A yet further alternative is that this plurality of generated parallel elongated focal areas are positioned in a cylindrical coordinates system, e.g. with a constant distance to a common axis of symmetry. A large number of variants on this theme are of course possible, said variants also falling within the preferred embodiments.

A plurality of parallel focal areas allow generation of a plurality of parallel, optically triggered, short-circuiting arc channels. This means in its turn that the current in each arc channel decreases, and, accordingly, the current dependent inductance, which means that the triggering process may be performed considerably more rapidly. At the same time, the electrodes contained in the electrode system are subjected to a decreased erosion as a consequence of local heating which each part arc gives rise to in those spots on the electrodes where the arc has its contact spots.

(V) A further type of focal area distribution may be formed by a plurality of focal areas, which are not parallel but mutually divergent or convergent. Thus, this enables the generated focal distributions to be adapted, and optimized, to the electrode geometry in question, and the electric field distribution associated thereto.

(VI) A further type of focal area distribution (figs 18a-b) may be formed by one or more elongated focal areas positioned along another line than the one forming the origi-

nally main direction of propagation of the radiant energy. This is of particular interest since one, in order to achieve as low triggering voltage as possible between two electrodes 23k, with a circular symmetrically focusing DE/DOE may need an electrode positioned symmetrically in cylindrical geometry just behind the DE/DOE, as seen in the main direction of propagation of the radiant energy, said electrode tending to shield a part of the radiant energy which has been deflected by the DE/DOE. A part of this radiant energy is, accordingly, lost and the radiant energy available for triggering decreases. DE/DOE which realize a non-centered focal distribution (which accordingly is separated from and is located parallel or non-parallel to the original main direction of propagation of the radiant energy) may be constructed for the purpose of avoiding these shielding effects. The design of the electrode system which should be possible to be short-circuited can in this way may be made much simpler and more efficient with DE/DOE generating plasmas displaced transversely in relation to axes of symmetry. This results immediately in improved possibilities to achieve triggering of the electrode gap and possibilities associated thereto to optimize the finally desirable electrical protection function. It should also be pointed out that such an electrode gap may be designed to be able to endure higher electrical breakthrough and discharge currents than a necessarily small electrode symmetrically placed after a circular symmetrically focusing DE/DOE.

(VII) A very important property of DE/DOE is that one can determine, already in the design thereof, where the resulting focal area is to start and stop respectively. In fig 11a z_1 and z_2 respectively denotes those two z-coordinates where as an example one single elongated focus "starts" and "stops" respectively. It is understood that at these two z-coordinates the energy density in the focal area exceeds and is lower respectively than a certain value, which for in-

stance may be defined by the threshold energy density of radiation induced ionisation and plasma formation in the medium in question. Thus, it is possible to control the resulting energy density distribution after the DE/DOE to exceed the energy density required for an electrical breakthrough generated by the radiant energy not until after a certain predefined distance, and to be lower than said energy density after a certain predefined distance, without decreasing the triggering action of the radiant energy. Thus, this allows the length of the elongated focal area to be accurately matched to the distance between the electrodes to be short-circuited. In addition, DE/DOE does not have to enter into contact with the electrical discharge, the plasma channel. Such a contact could cause damages on the DE/DOE since electrical discharges could occur on the surface thereof and there give rise to function reducing material damages and plasma constituents could be condensed on the surface thereof, which easily could influence the function of the DE/DOE negatively.

In the embodiment according to fig 8 the radiant energy is supplied through an opening 29f in one of the electrodes as before. Fig 13 illustrates a variant where, generally, the only difference compared to the embodiment according to fig 8 is that here the diffractive optical element (kinoform) 36g is placed radially outwardly of one of the electrodes 23g. The optical element 36g is as before designed to deflect the laser light and focus the same in a number of spots distributed along the electrical conduction path aimed at between the electrodes. The bunches of rays forming the spots 28g have each their own deflection angle. Thus, the bunches of rays move different distances to the spots 28g respectively. The advantage in locating the kinoform 36g according to fig 13 at the side of one of the electrodes is that the kinoform will be located at the side of the highest electrical field such that field disturbances become mini-

mal. The electrode design is also simplified since no opening for the laser light is required.

Fig 14 illustrates a variant where the optical system 27h presents an axicone 37h (refractive or diffractive) which divides the radiation arriving from a laser or similar into parts and directs these beam parts to diffractive elements (kinoforms 36h). These kinoforms are distributed around one of the electrodes, namely the one denoted 23h in fig 14. In fig 15 the same structure as in fig 14 is shown in perspective. It appears in fig 15 that 4 kinoforms 36h in the embodiment are arranged around the electrode 23h for causing the radiant energy to be focused by diffraction in a number of spots or areas 28h present along the axis of symmetry between the electrodes. The use of a plurality of discrete kinoforms 36h should be more simple and non-expensive to realize than a continuously annular kinoform, even if the latter wouldn't be impossible.

It should be noted that the description presented hereinabove only should be considered as exemplifying for the inventive idea, on which the invention is built. Thus, it is obvious for the men skilled in the art that detailed modifications may be made without leaving the scope of the invention. As an example, it may be mentioned that according to the invention, it is not necessary to use a laser for supply of ionising/plasma forming energy to the gap 24. Also other radiative sources, for example electron guns, or other energy supply solutions may be applied as long as the rapidness and reliability demands according to the invention are fulfilled. It should be observed that the switch means 10 may according to the invention be applied for protection of electric objects against fault-related over-currents also in other operative cases than the ones illustrated in Figs 1, 3 and 5, where the device according to the invention is arranged in order to reduce the negative effects of the rela-

tively slow breaking time of the circuit breaker 4. Thus, the switch means according to the invention does not necessarily need to be operation-related to such a circuit breaker 4. It should be observed that the invention is well suited for alternating current as well as direct current. Finally, the switching arrangement must not necessarily be used for protection purposes.

Claims

1. A device for switching electric power comprising at least one electric switching arrangement, characterized in that the switching arrangement (5), comprises at least one switch means (10), which comprises an electrode gap (24), which is convertible between an electrically substantially isolating state and an electrically conducting state, and means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity and that said means (25) for causing or at least initiating the electrode gap to assume conductivity are adapted to supply energy to the electrode gap in the form of radiant energy to bring the gap or at least a part thereof to the shape of a plasma.

2. A device according to any preceding claim, characterized by said means (25) for causing or at least initiating the electrode gap or a part thereof to assume electrical conductivity comprising at least one laser (25).

3. A device according to any preceding claim, characterized in that the switch means (10) is formed in such a way that an electric field is present in its isolating condition between its electrodes (23), which field promotes or generates an electric flash-over between the electrodes on causing or initiating the electrode gap to assume electrical conductivity.

4. A device according to claim 3, characterized in that the electric field in the isolating condition of the electrode gap (24) has substantially less field strength than the field strength, at which a spontaneous breakthrough takes place.

5. A device according to claim 3 or 4, characterized in that the electric field in the insulating condition of the electrode gap (24) has a field strength which is not more than 30%, suitably not more than 20% and preferably not more than 10% of the field strength, at which a spontaneous breakthrough takes place.

6. A device according to any of the claims 3-5, characterized in that the electric field in the insulating condition of the electrode gap (24) has a field strength which is at least 0,1%, suitably at least 1%, and preferably at least 5%, of the field strength, at which a spontaneous breakthrough takes place.

7. A device according to any preceding claim, characterized in that the means (25) for causing or at least initiating the electrode gap (24) to assume electrical conductivity are arranged to supply the radiant energy in such a manner that the lowest electrical field strength, at which the electrode gap may be triggered to assume electrical conductivity, is minimized.

8. A device according to any preceding claim, characterized in that the means (25) for causing or at least initiating the electrode gap (24) to assume electrical conductivity are arranged to supply the radiant energy to the electrode gap in a such a manner that a time delay between the arriving radiant energy and a developed conductive ability of the electrode gap is minimized.

9. A device according to any preceding claim, characterized in that the switch means (10) and the means (25) for causing or at least initiating the electrode gap to assume electric conductivity are arranged such that the establishment of the electric conductivity in the electrode gap is substantially

independent of the electric field strength present between the electrodes of the switch means in its insulating state.

10. A device according to any preceding claim, characterized in that the means (25) for supplying triggering energy to the electrode gap are arranged to apply the radiative energy on or at least in the vicinity of at least one of the electrodes (23).

11. A device according to any preceding claim, characterized in that the means (25) for supplying triggering energy to the electrode gap are arranged to locate the radiative energy in one spot or area in the gap (24) between the electrodes (23).

12. A device according to any preceding claim, characterized in that the members (25, 27) for supplying the triggering energy to the electrode gap are arranged to apply the radiant energy in two or more spots or areas (28) between the electrodes.

13. A device according to claim 12, characterized in that the means for supplying triggering energy to the electrode gap are arranged to locate said two or more spots or areas of radiant energy along a line extending between the electrodes, said line corresponding to the extent of an electric conduction path desired between the electrodes.

14. A device according to any preceding claim, characterized in that the means (25) for supplying triggering energy to the electrode gap are arranged to apply the radiant energy in one or more elongated areas (28i,k, m, n), the longitudinal axes of which extend substantially along the direction of the electric conduction path which is intended between the electrodes.

15. A device according to claim 14, characterized in that the means (27) for supplying triggering energy to the electrode gap are adapted to shape the elongated focal area into a tubular shape.

16. A device according to claim 14 or 15, characterized in that the means for supplying triggering energy to the electrode gap are adapted to shape the elongated area so that it bridges, entirely or substantially entirely, the space between the electrodes.

17. A device according to any of claims 14 or 15, characterized in that the means (27) for supplying triggering energy to the electrode gap are adapted to form two or more elongated focal areas (28) in the electrode gap, said focal areas being located longitudinally after each other along the electric conduction path intended between the electrodes.

18. A device according to any of claims 1 and 10, characterized in that the means for supplying triggering energy to the electrode gap are adapted to apply the radiant energy on at least one of the electrodes as well as between them.

19. A device according to any of the claims 10-18, characterized in that at least one of the electrodes at the electrode gap has an opening (29), through which the means (25) for supplying triggering energy are arranged to direct the radiative energy.

20. A device according to claims 15 and 19, characterized in that the means (27) for supplying triggering energy to the electrode gap are adapted to locate the tubular radiant energy area (28) in the vicinity of that electrode which has an opening (29) and such that the axis of the tubular radiant energy area is substantially concentric to the axis of the opening in the electrode.

21. A device according to any of claims 10-20, characterized in that the means for supplying triggering energy to the electrode gap comprise a system for controlling electromagnetic wave energy.

22. A device according to claim 21, characterized in that the control system comprises at least one diffractive element.

23. A device according to claim 22, characterized in that the diffractive element is formed by a kinoform.

24. A device according to any of claims 21-23, characterized in that the control system (27f) is located radially outwardly of the electrodes and adapted to direct bunches of rays towards the gap between the electrodes.

25. A device according to any of claims 21-24, characterized in that the control system (27h) is adapted to divide radiant energy pulses into an annular configuration about one of the electrodes.

26. A device according to any preceding claim, characterized in that the switching arrangement is connected to protect an electric object (1) from fault-related current/voltages and that the switching arrangement is actuatable for effecting its protection function with the assistance of a fault-conditions detecting arrangement (11-13).

27. A device according to claim 26, characterized in that the switching arrangement (5) is adapted for diversion of over-currents to earth (8) or otherwise another unit having a relatively low potential.

28. A device according to any preceding claim, characterized in that at least one over-voltage diverter (22) is connected in parallel to the switch means (10).

29. A device according to claim 27, wherein the electric object (1) is connected to an electric power network (3) or another equipment included in the electric power plant, the device comprising a switching device (4) in a line (2) between the object and the network/equipment, characterized in that the switch means (10) is connected to the line (2) between the object (1) and the switching device (4), and that the switch means (10) is actuatable for over-current diversion within a time period substantially shorter than the break-time of the switching device (4).

30. A device according to claim 29, characterized in that the switching device (4) is formed by a circuit breaker.

31. A device according to claim 30, characterized in that it comprises a further breaker (6) arranged in the line between the switching device (4) and the object, said further breaker being arranged between the switching means (10) and the object (1) and being adapted to break lower voltages and currents than the switching device (4) and therefore capable of performing a shorter break-time than the switching device and that the further breaker is adapted to break when the over-current towards or away from the object (1) has been reduced by means of the switch means (10) but substantially earlier than the switching device.

32. A device according to claim 31, characterized in that it comprises a control unit (14) connected to the detecting arrangement (11-13) and to the further breaker (6) in order to achieve actuation of the further breaker for breaking purposes when the over-current towards or away from the object

(1) is indicated, by means of the detecting arrangement, to be below a predetermined level.

33. A device according to any of the claims 31-32, characterized in that the further breaker (6) comprises a switch (15) over which there is coupled a shunt line (17) having one or more components (18) for avoiding arcs on separation of contacts of the switch (15) by causing the shuntline (17) to take over current conduction from the contacts.

34. A device according to claim 33, characterized in that said one or more components (18) in the shunt line (17) are closable into conduction by means of control via the control unit (14).

35. A device according to claim 33 or 34, characterized in that said one or more components (18) are formed by controllable semiconductor components.

36. A device according to any of the claims 33-35, characterized in that said one or more components (18) are provided with at least one over-voltage arrester (30).

37. A device according to any of the claims 33-36, characterized in that a disconnector (20) for galvanic separation is arranged in series with said one or more components (18).

38. A device according to claim 37, characterized in that the disconnector (20) is coupled to the control unit (14) to be controlled thereof for opening after the switch (15) having been controlled to have closed and said one or more components (18) having been placed in a condition for breaking the shunt line (17).

39. A device according to any preceding claim, characterized in that the protected object (1) is formed by an electric apparatus with a magnetic circuit.

40. A device according to claim 38, characterized in that the object is formed by a generator, transformer or motor.

41. A device according to any of the preceding claims, characterized in that the object is formed by a power line, e.g. a cable.

42. A device according to any preceding claim, characterized in that two switch means (10) are arranged on either sides of the object to protect the same from two sides.

43. A device according to claim 1, characterized in that it comprises a control unit (14) connected to the switch means (10) and to the over-current conditions detecting arrangement (11-13), said control unit (14) being arranged to control the switch means to closing based upon information from the over-current conditions detecting arrangement when required for reasons of protection.

44. A device according to claim 43 and one or more of the claims 32, 33 and 38, characterized in that one and the same control unit (14) is arranged to control, based upon information from the over-current conditions detecting arrangement (11-13), the switch means (10) and the further breaker (6).

45. Use of a device according to any preceding claim for protection of an object against fault-related over-currents.

46. A device according to any preceding claim, characterized in that the means for supplying triggering energy to the electrode gap are adapted to focus the radiant energy in a

plurality of substantially parallel, elongated focal areas, the longitudinal axes of which are located substantially along the direction of the electrical conduction path aimed at between the electrodes.

47. A method in an electric power plant for protection of an electric object (1) from fault-related over-currents, characterized in that over-current diversion is accomplished by means of a switch means (10) when over-current conditions have been detected by means of an arrangement (11-13) for such detection, said switch means (10), which is arranged for diversion of over-currents to earth (8) or otherwise another unit with a relatively low potential, being closed for over-current diversion by imparting an electrode gap (24), which is present in the switch means, electrical conductivity by supply of radiant energy to the electrode gap with the aid of triggering means (25).

48. A method according to claim 47, characterized in that a further breaker (6), which is arranged in a line (2) between a switching device (4) and the object (1) and between the switch means (10) and the object (1), is actuated for breaking after the over-current towards or away from the object (1) having been reduced by means of the switch means (10).

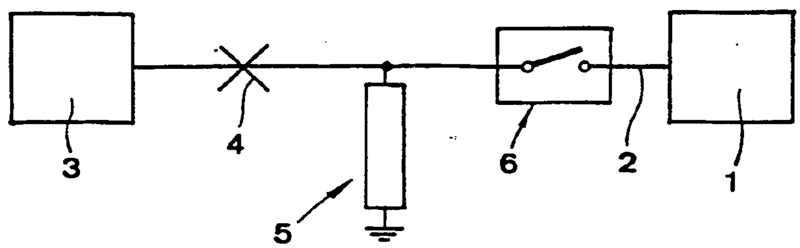

Fig 1

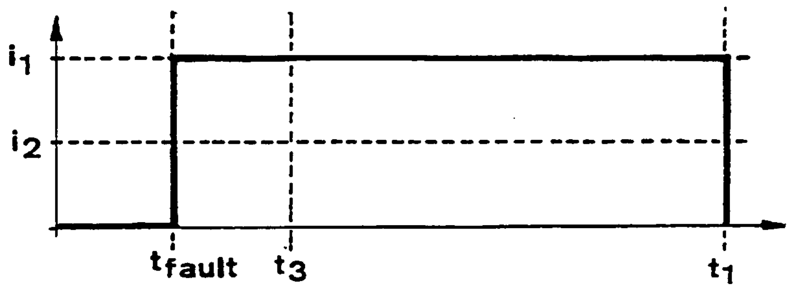

Fig 2a

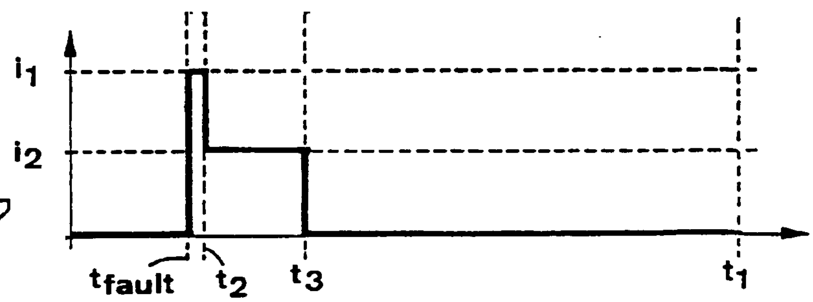

Fig 2b

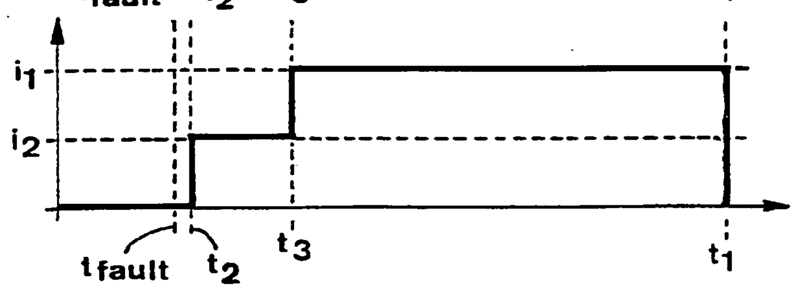

Fig 2c

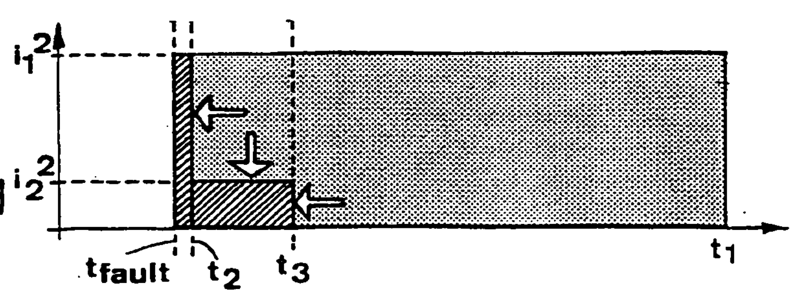

Fig 2d

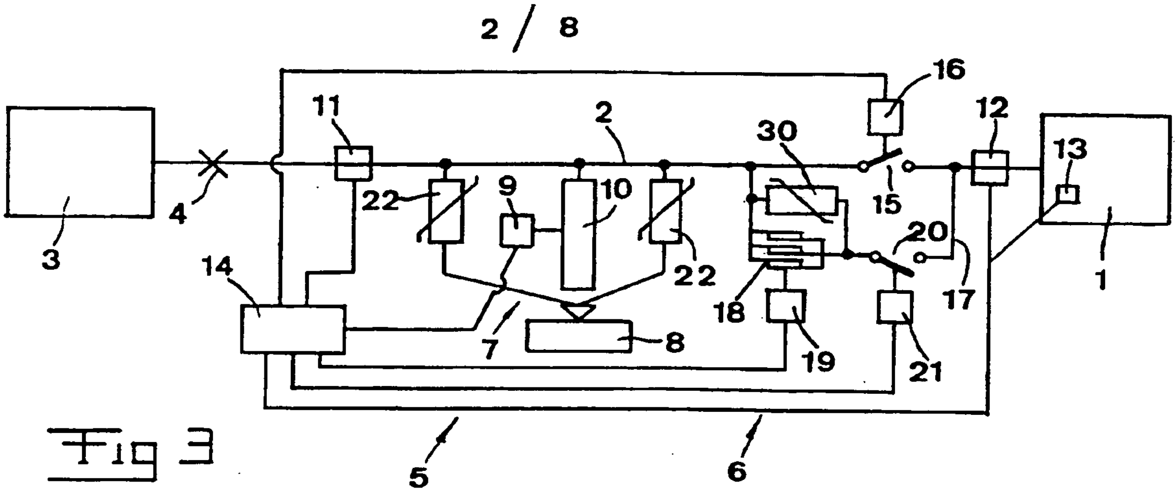

Fig 3

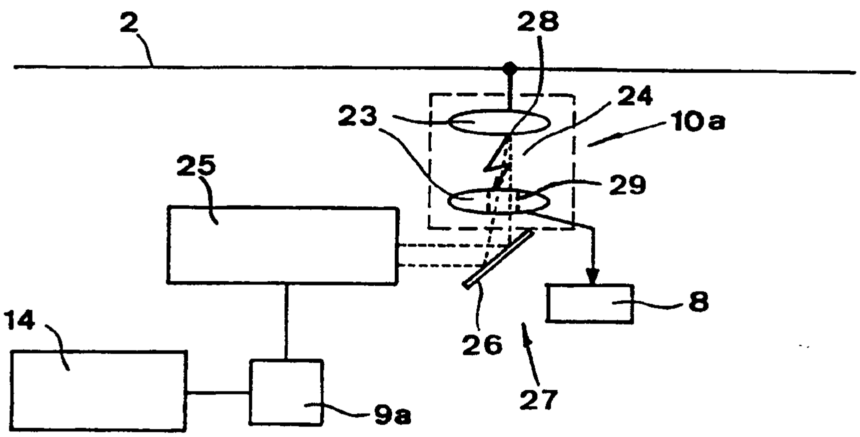

Fig 4

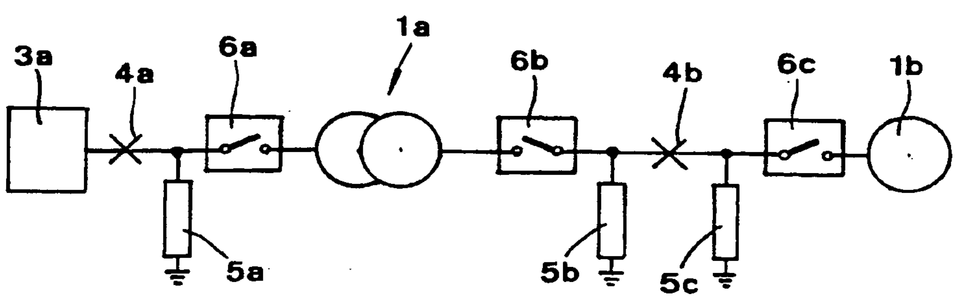

Fig 5

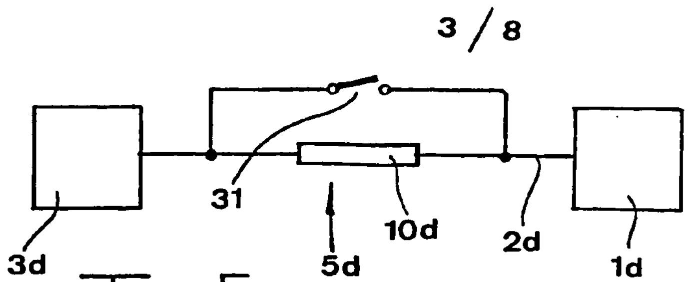

Fig 6

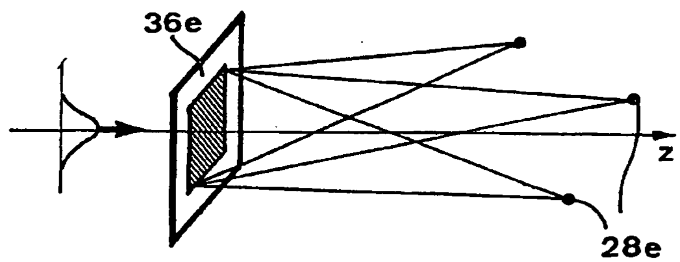

Fig 7a

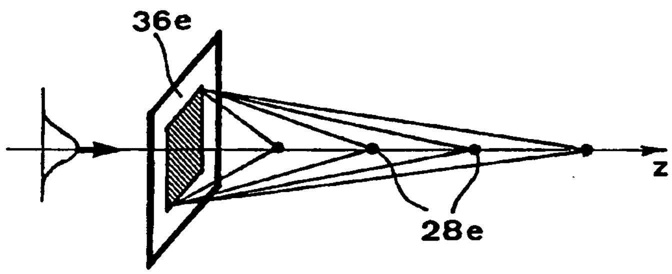

Fig 7b

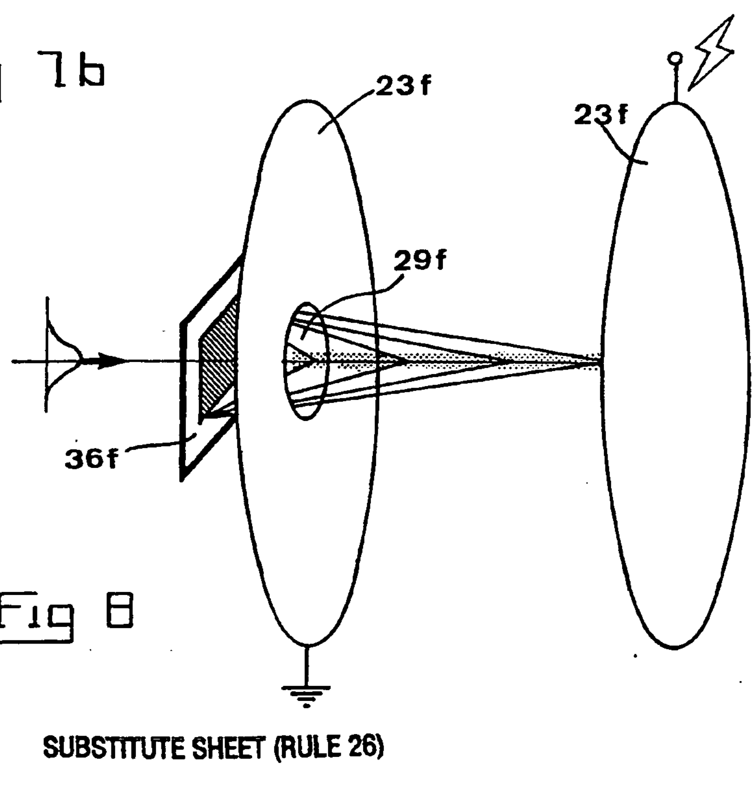

Fig 8

Fig 9

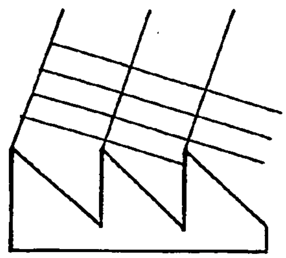

Fig 10a

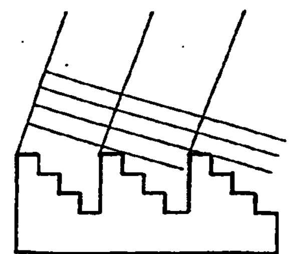

Fig 10b

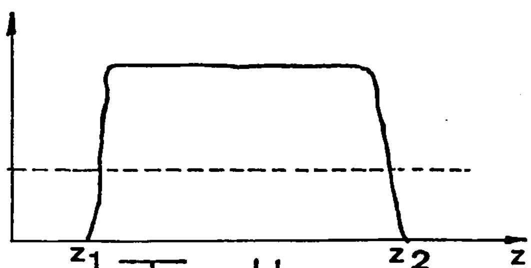

Fig 11a

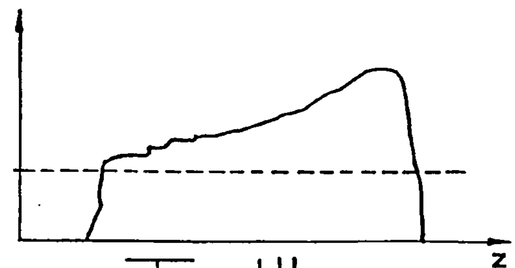

Fig 11b

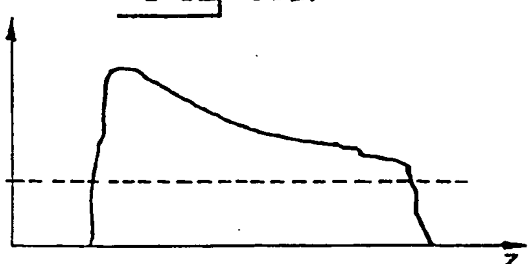

Fig 11c

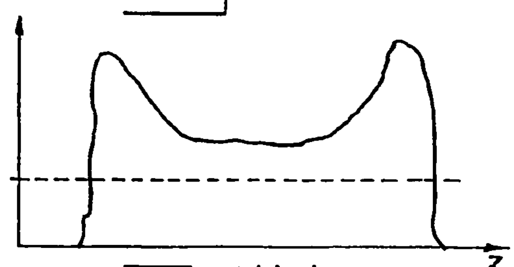

Fig 11d

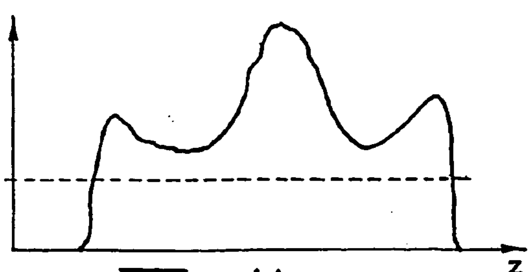

Fig 11e

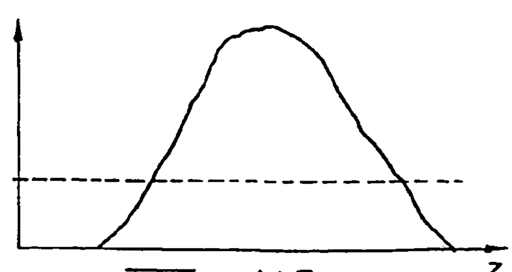

Fig 11f

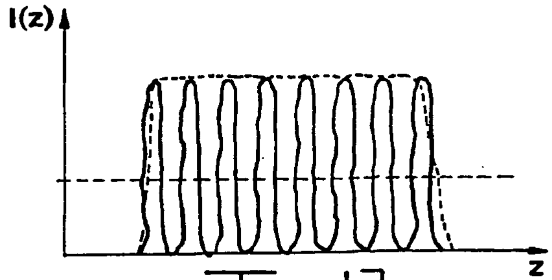

Fig 12a

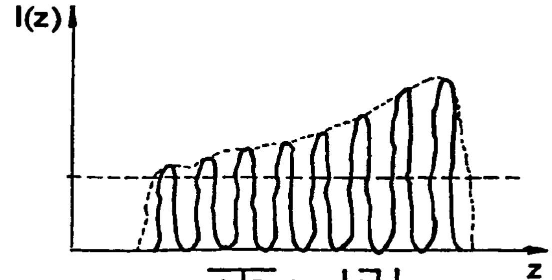

Fig 12b

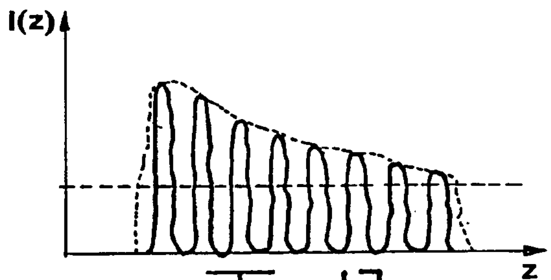

Fig 12c

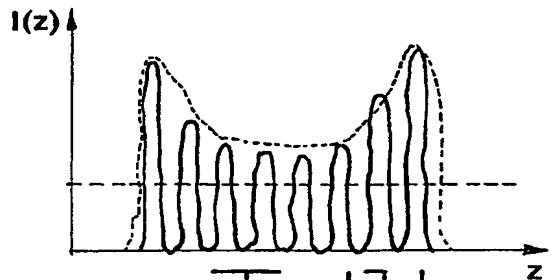

Fig 12d

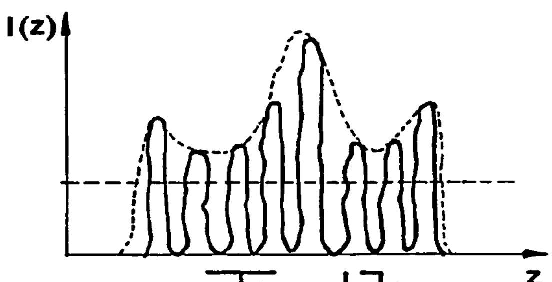

Fig 12e

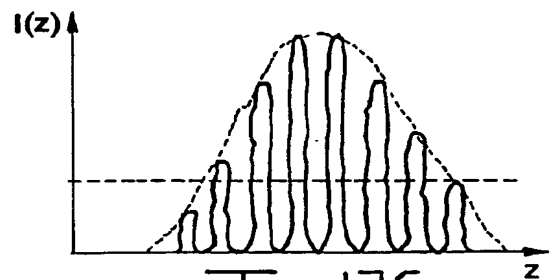

Fig 12f

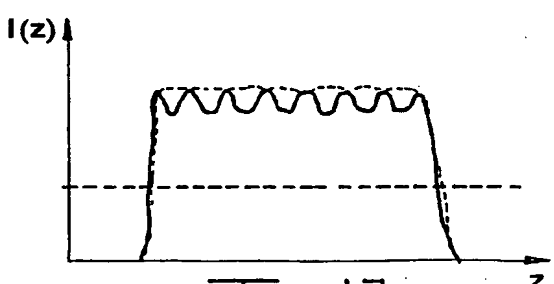

Fig 12g

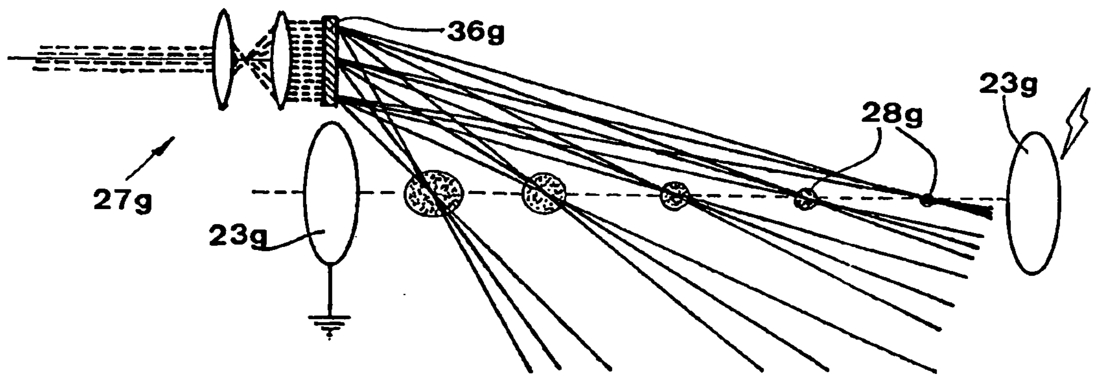

Fig 13

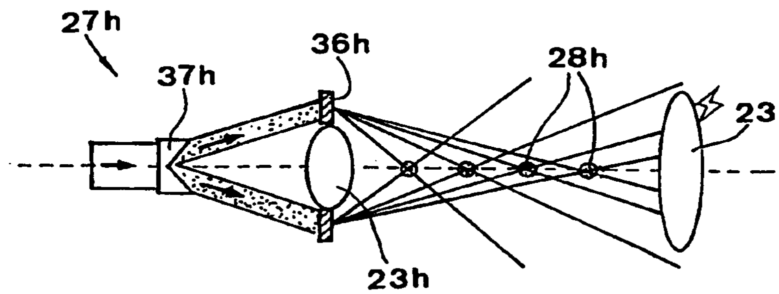

Fig 14

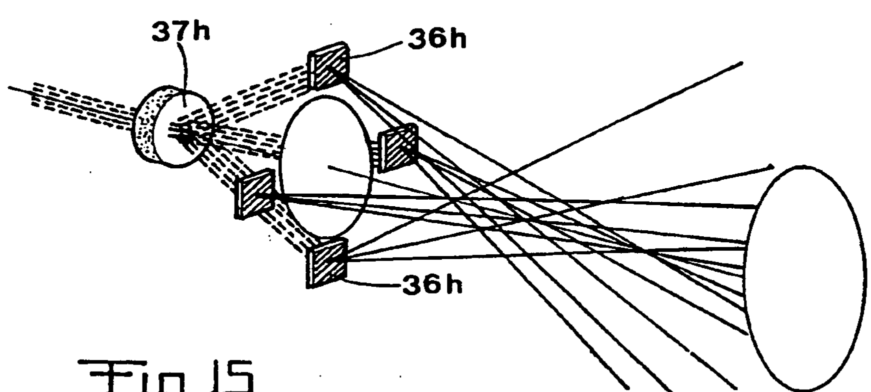

Fig 15

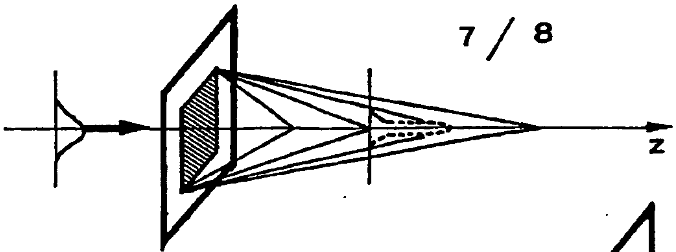

Fig 16a

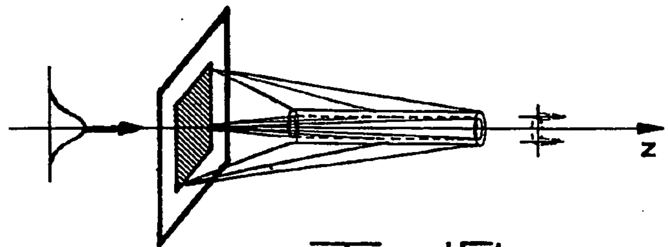

Fig 16b

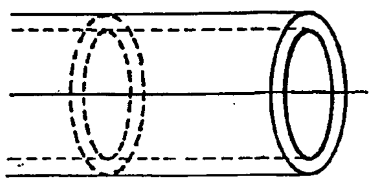

Fig 16c

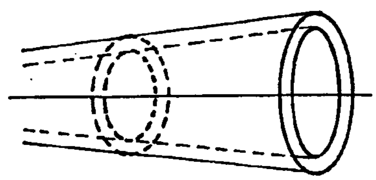

Fig 16d

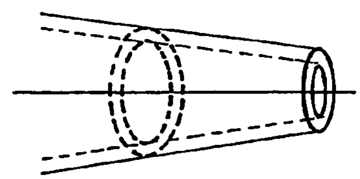

Fig 16e

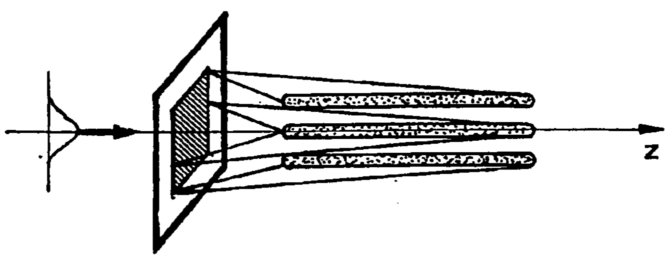

Fig 17a

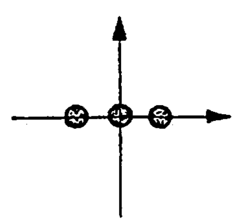

Fig 17b

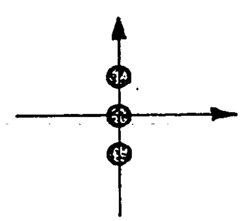

Fig 17c

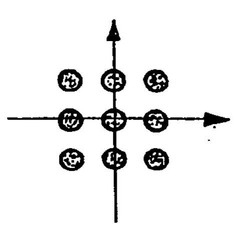

Fig 17d

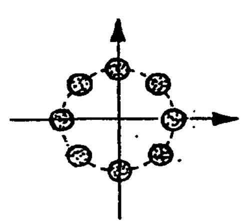

Fig 17e

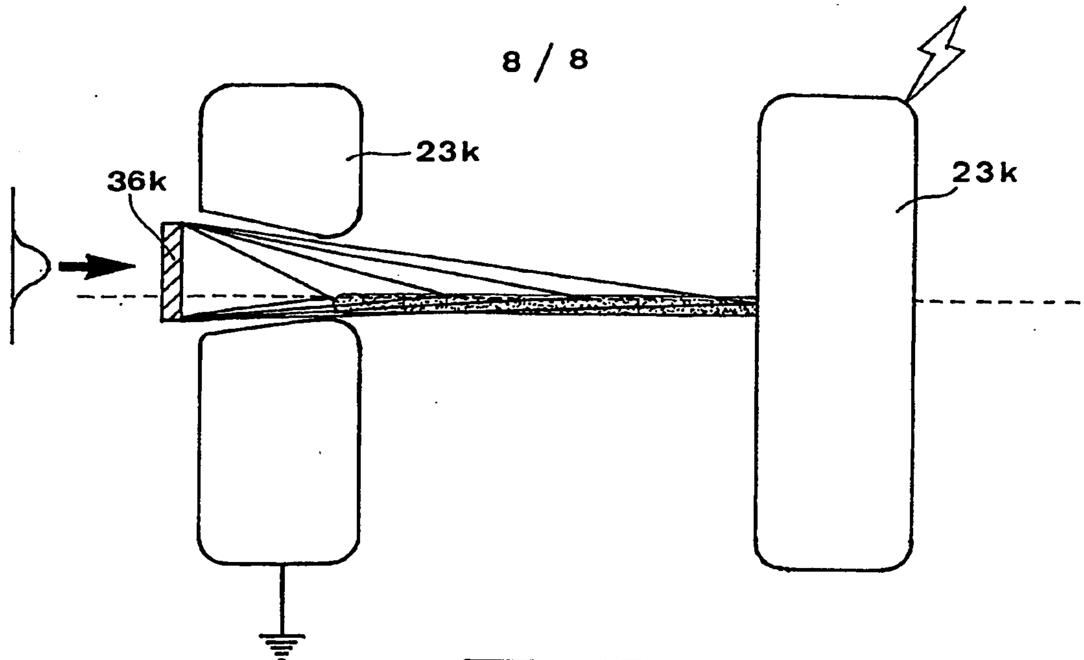

Fig 18a

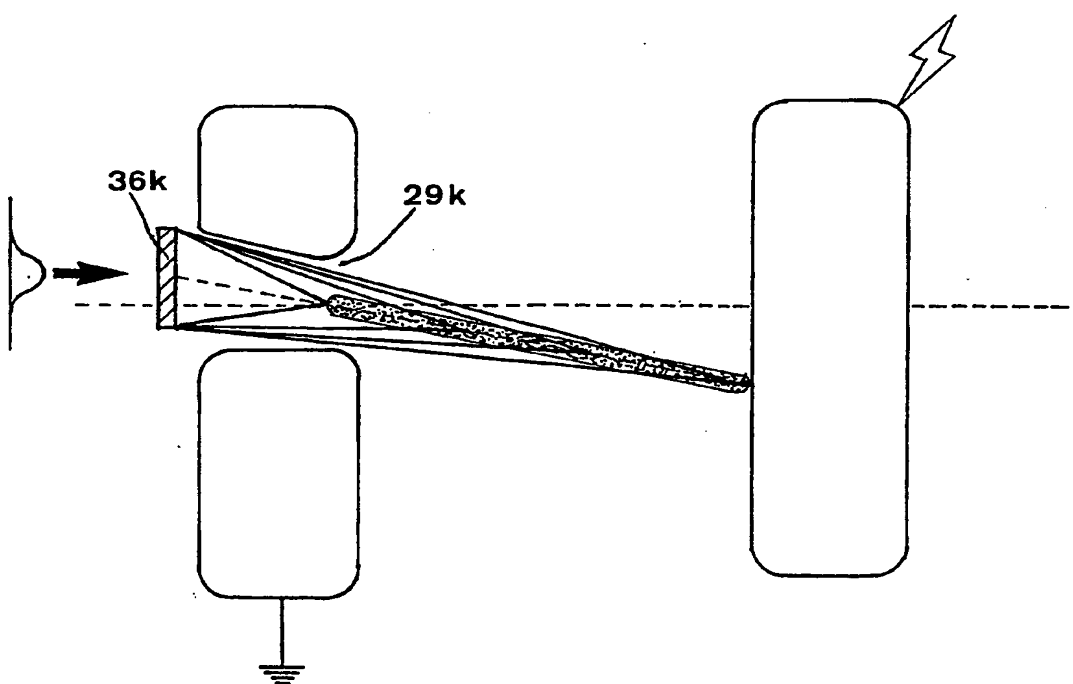

Fig 18b

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(74) Agents: BJERKÉN, Håkan et al.; Bjerkéns Patentbyrå KB, P.O. Box 1274, S-801 37 Gävle (SE).

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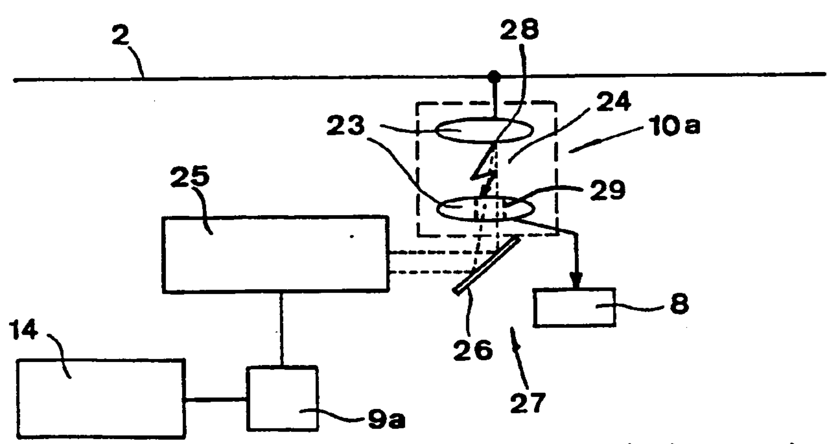
(54) Title: SWITCHING DEVICE INCLUDING SPARK GAP FOR SWITCHING ELECTRICAL POWER, A METHOD FOR PROTECTION OF AN ELECTRIC OBJECT AND ITS USE

(57) Abstract



A device for switching electric power comprises at least one electric switching arrangement (5). This switching arrangement comprises at least one switching element (10a) comprising an electrode gap (24). This gap is convertible between an electrically substantially insulating state and an electrically conducting state. Furthermore, the switching element comprises means (25) for causing or at least initiating the electrode gap or at least a part thereof to assume electrical conductivity. The means (25) for causing or at least initiating the electrode gap to assume conductivity are adapted to supply energy to the electrode gap in the form of radiation energy to bring the gap or at least a part thereof to the form of a plasma by means of this radiation energy.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/02152

A. CLASSIFICATION OF SUBJECT MATTER

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According to International Patent Classification (IPC) or to both national classification and IPC

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5399941 A1 (M.G. GROTHAUS ET AL.), 21 March 1995 (21.03.95), column 1, line 10 - line 15; column 3, line 8 - line 28; column 3, line 39 - line 55, ; column 4, line 20 - line 35, line 46 - line 54, figures 2-5, abstract	1-4,10-16, 19-22,25,28, 46,
Y		7,9,26-27, 29-32,39-45, 47-48
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Y		7,9,26-27, 29-32,39-45, 47-48
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X	US 4484106 A1 (R.S. TAYLOR ET AL.), 20 November 1984 (20.11.84), column 2, line 10 - line 16; column 2, line 26 - line 38; column 4, line 21 - line 30, ; column 5, line 7 - line 14, line 32 - line 44; column 6, line 41 - line 46, figure 11	1-4,10-12, 21-22,24,28
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